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Issue 121

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The theories of Stephen Hawking

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The hunt for life elsewhere in the universe still rages on, as you'll discover in our cover feature this month. Turn to page 14 for full details on the missions, techniques and plans in our search for life beyond planet Earth. Are we any closer to finding it?

Elsewhere in the issue, your regulars are all here, including mysteries of the universe - where we go back to 1054 and reveal what caused the explosion that formed the Crab Nebula - your burning questions answered in Ask Space and this month's guide to the night sky, where we tour Clavius crater on the surface of the Moon. There's also naked-eye and binocular tours of some of the brightest stars in the constellations of Auriga, Taurus and their borders.

Also this month, we explore the surface and interior of the seventh world from the Sun, ice giant Neptune, reveal some of the greatest space innovations that will help us conquer the cosmos and get into the nitty gritty of some of Stephen Hawking's most groundbreaking theories - some of which have revolutionised the way we view the universe, while others are still leaving scientists scratching their heads.

Enjoy the issue, and don't forget to check out our exclusive interview with astronaut Tim Peake, who reveals more about his life after returning from space in June 2016.

GEMMA LAVENDER
EDITOR-IN-CHIEF

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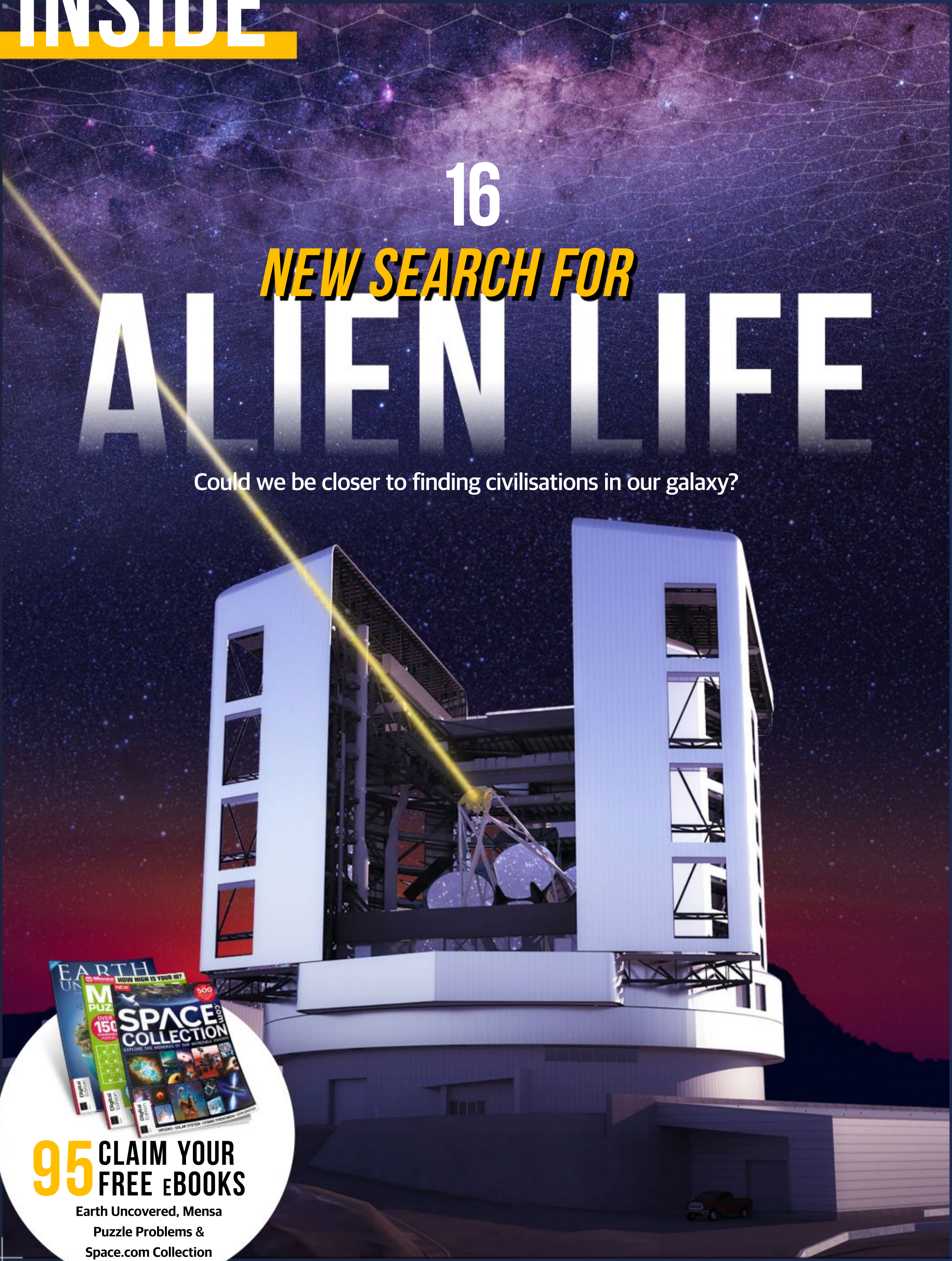

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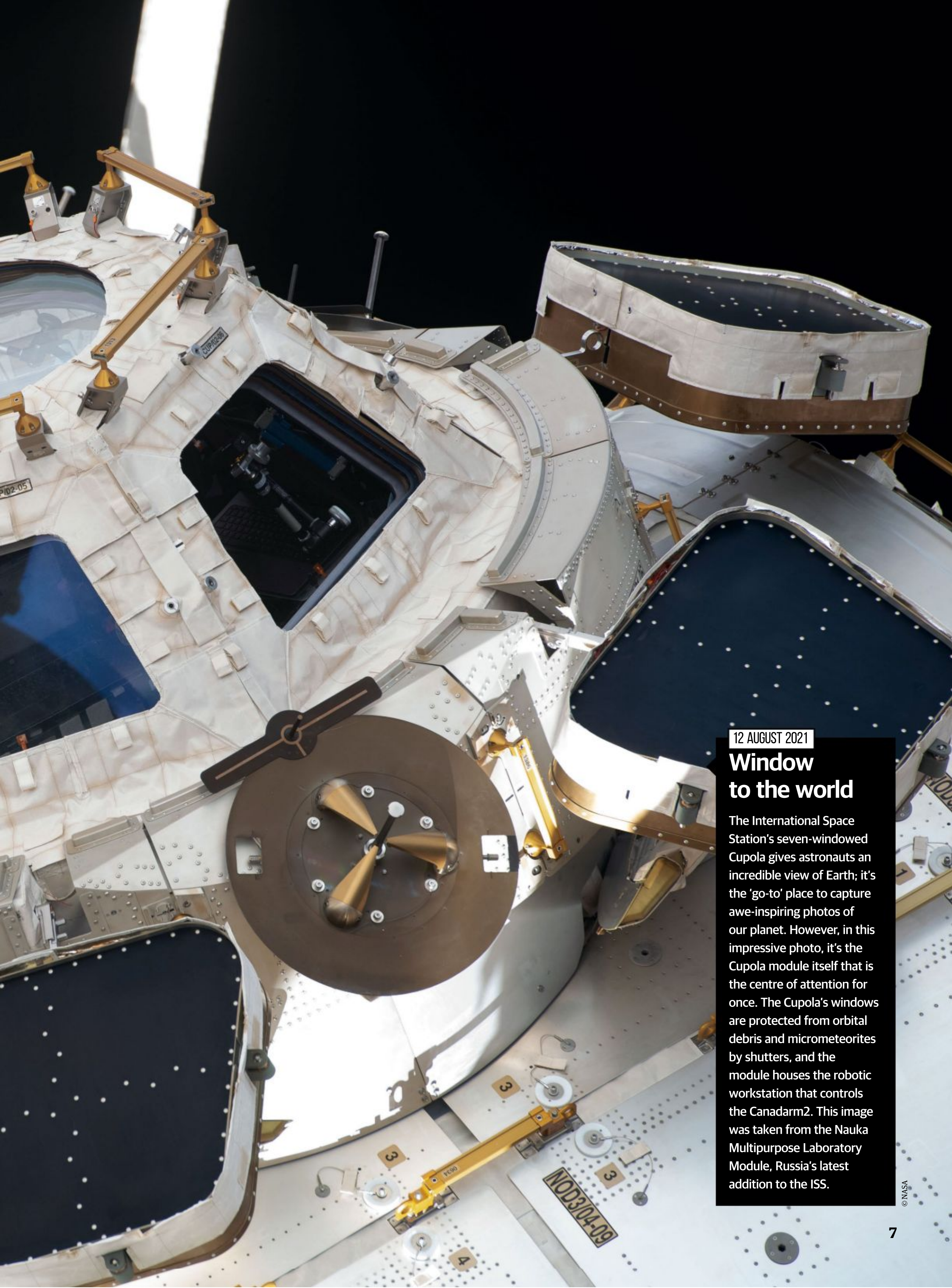

12 AUGUST 2021

Window to the world

The International Space Station's seven-windowed Cupola gives astronauts an incredible view of Earth; it's the 'go-to' place to capture awe-inspiring photos of our planet. However, in this impressive photo, it's the Cupola module itself that is the centre of attention for once. The Cupola's windows are protected from orbital debris and micrometeorites by shutters, and the module houses the robotic workstation that controls the Canadarm2. This image was taken from the Nauka Multipurpose Laboratory Module, Russia's latest addition to the ISS.

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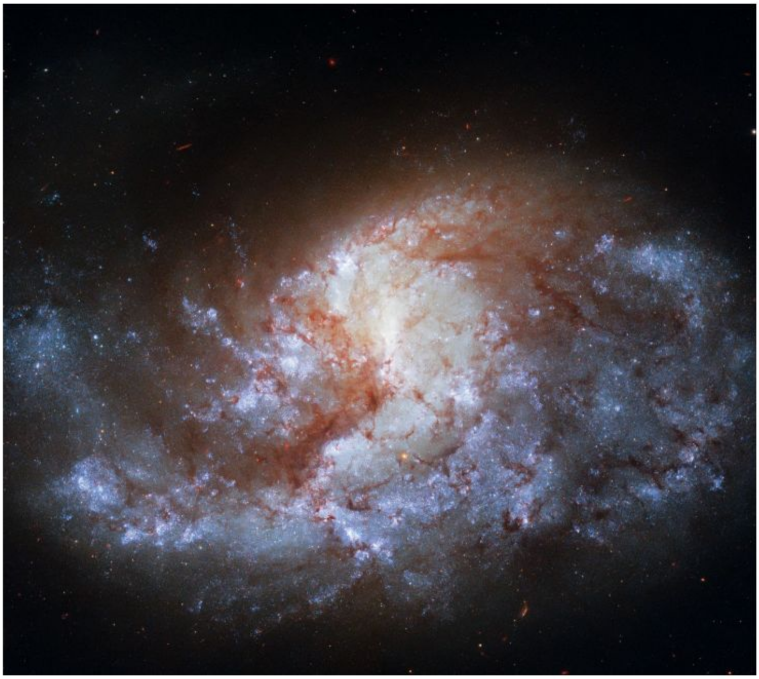

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16 AUGUST 2021

Cosmic furnace

This glowing galactic jewel, NGC 1385, is around 70,000 light years in diameter and is located approximately 68 million light years away from Earth within the constellation of Fornax. Unlike numerous other constellations in our skies, Fornax is not named after an animal, an ancient god or hero of legend – it is the Latin word for furnace.

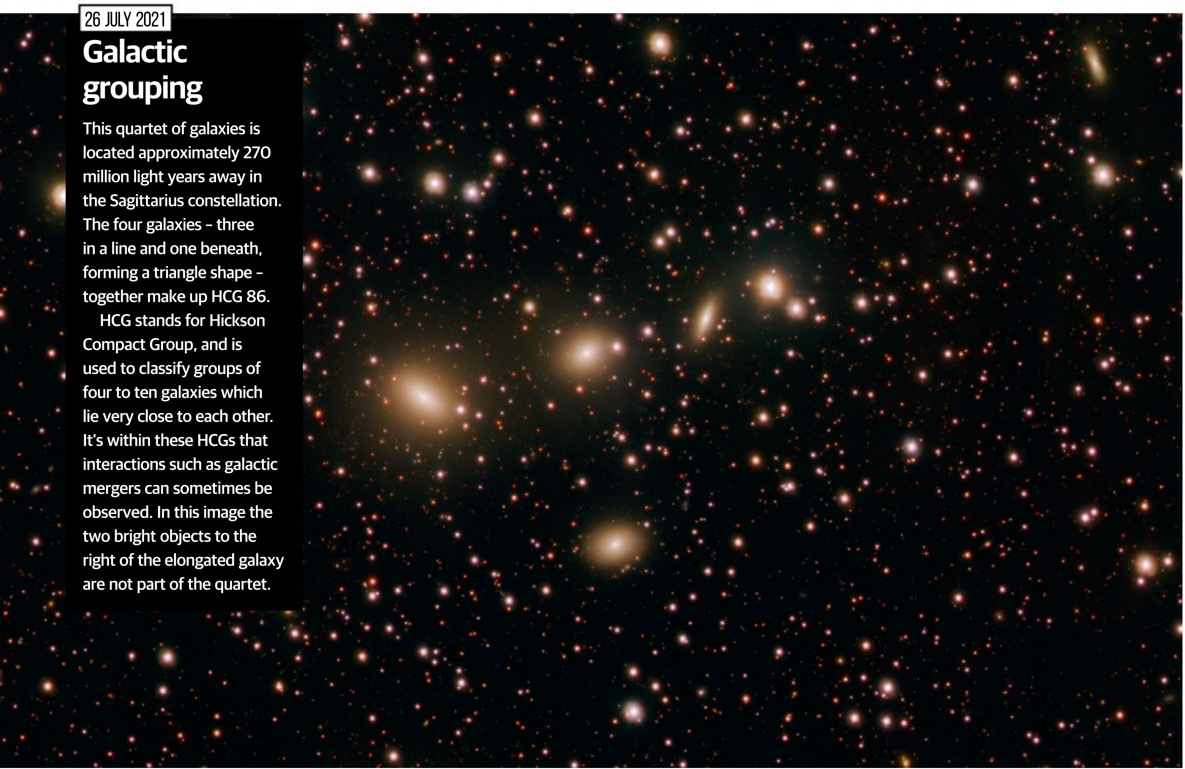
NGC 1385 was discovered on 17 November 1784 by astronomer William Herschel and belongs to a group which contains over 30 galaxies. This impressive image was captured by the Hubble Space Telescope's Wide Field Camera 3.

26 JULY 2021

Galactic grouping

This quartet of galaxies is located approximately 270 million light years away in the Sagittarius constellation. The four galaxies – three in a line and one beneath, forming a triangle shape – together make up HCG 86.

HCG stands for Hickson Compact Group, and is used to classify groups of four to ten galaxies which lie very close to each other. It's within these HCGs that interactions such as galactic mergers can sometimes be observed. In this image the two bright objects to the right of the elongated galaxy are not part of the quartet.



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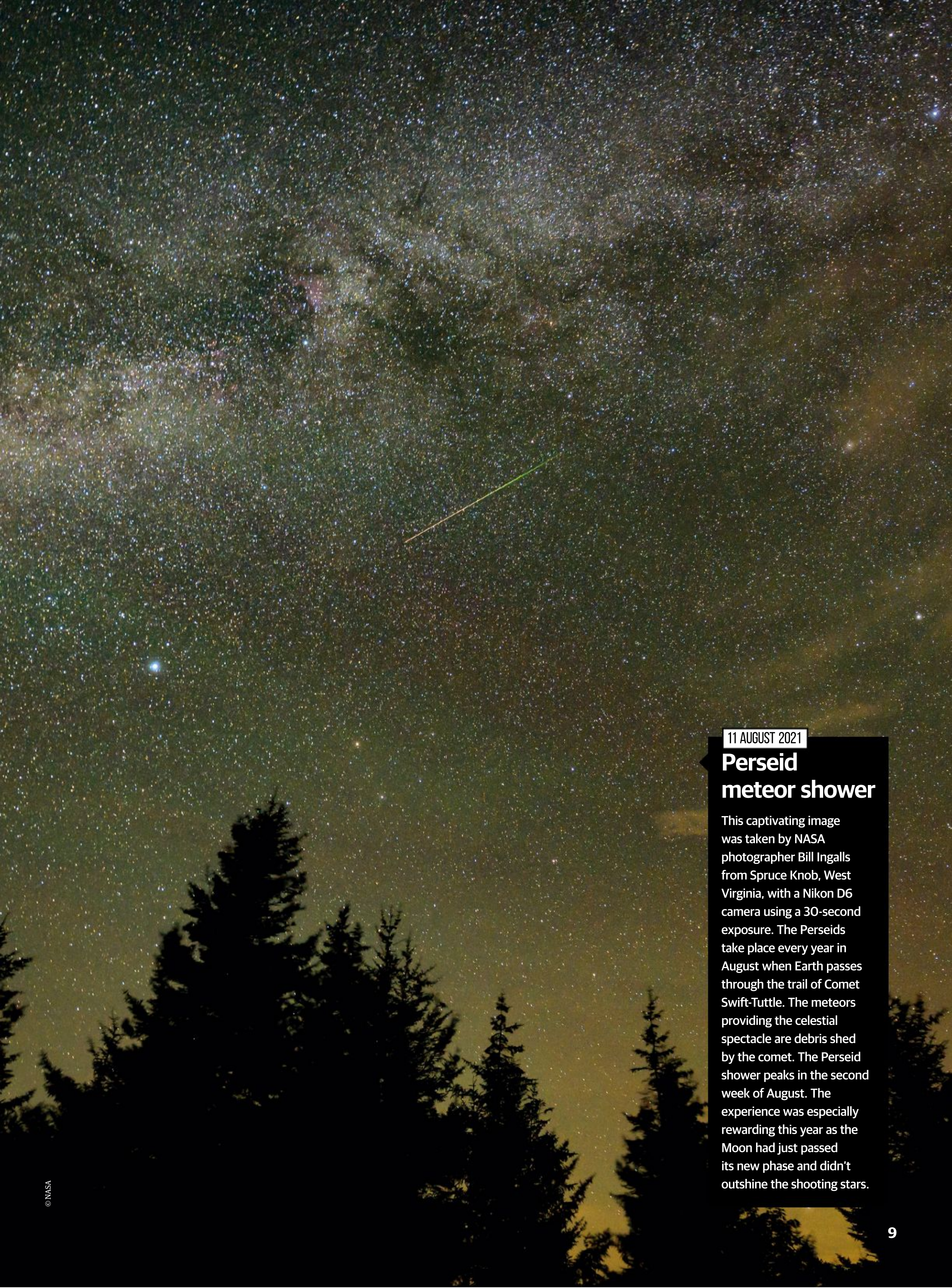

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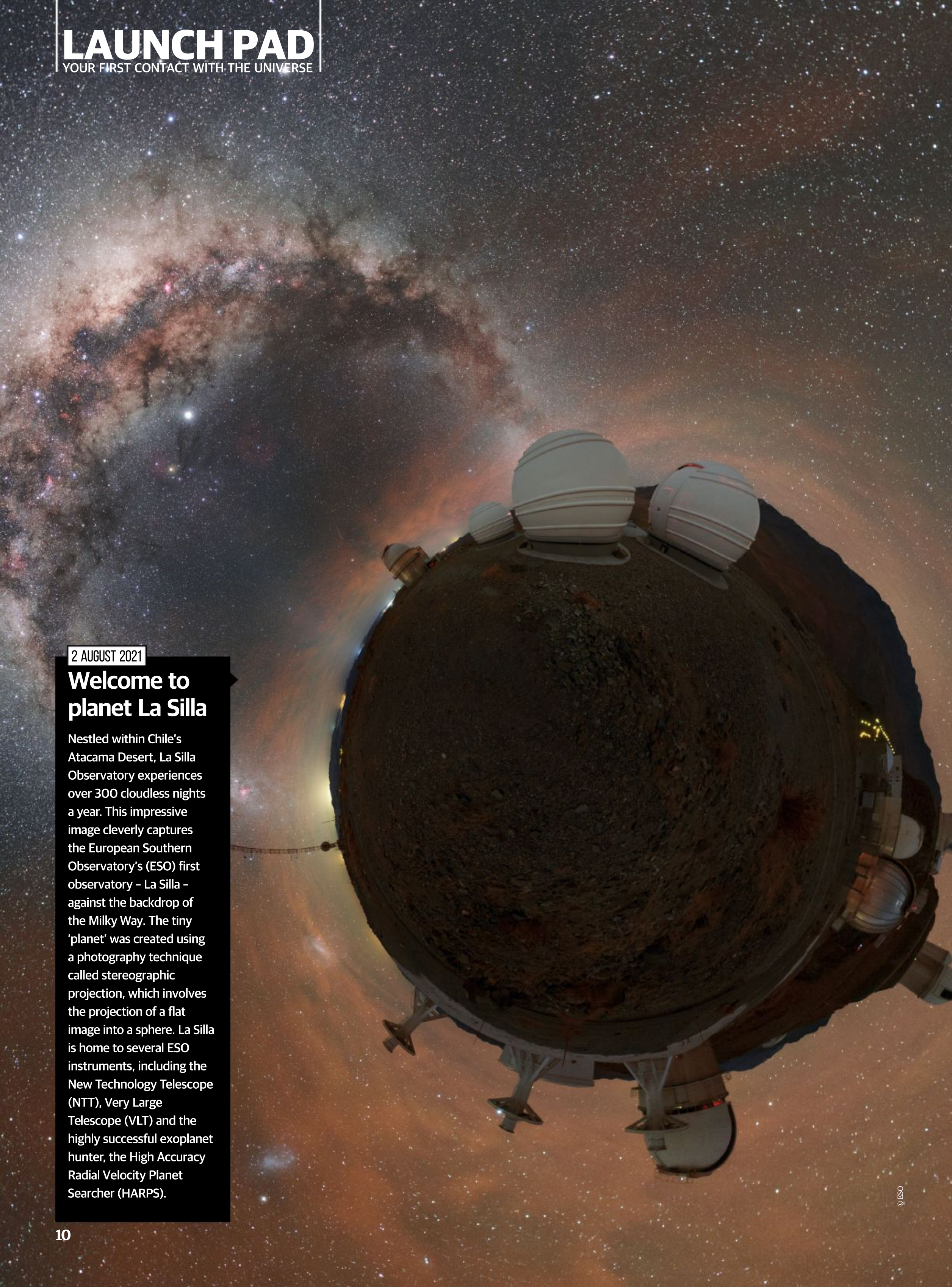
11 AUGUST 2021

Perseid meteor shower

This captivating image was taken by NASA photographer Bill Ingalls from Spruce Knob, West Virginia, with a Nikon D6 camera using a 30-second exposure. The Perseids take place every year in August when Earth passes through the trail of Comet Swift-Tuttle. The meteors providing the celestial spectacle are debris shed by the comet. The Perseid shower peaks in the second week of August. The experience was especially rewarding this year as the Moon had just passed its new phase and didn't outshine the shooting stars.



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Welcome to planet La Silla

Nestled within Chile's Atacama Desert, La Silla Observatory experiences over 300 cloudless nights a year. This impressive image cleverly captures the European Southern Observatory's (ESO) first observatory – La Silla – against the backdrop of the Milky Way. The tiny 'planet' was created using a photography technique called stereographic projection, which involves the projection of a flat image into a sphere. La Silla is home to several ESO instruments, including the New Technology Telescope (NTT), Very Large Telescope (VLT) and the highly successful exoplanet hunter, the High Accuracy Radial Velocity Planet Searcher (HARPS).

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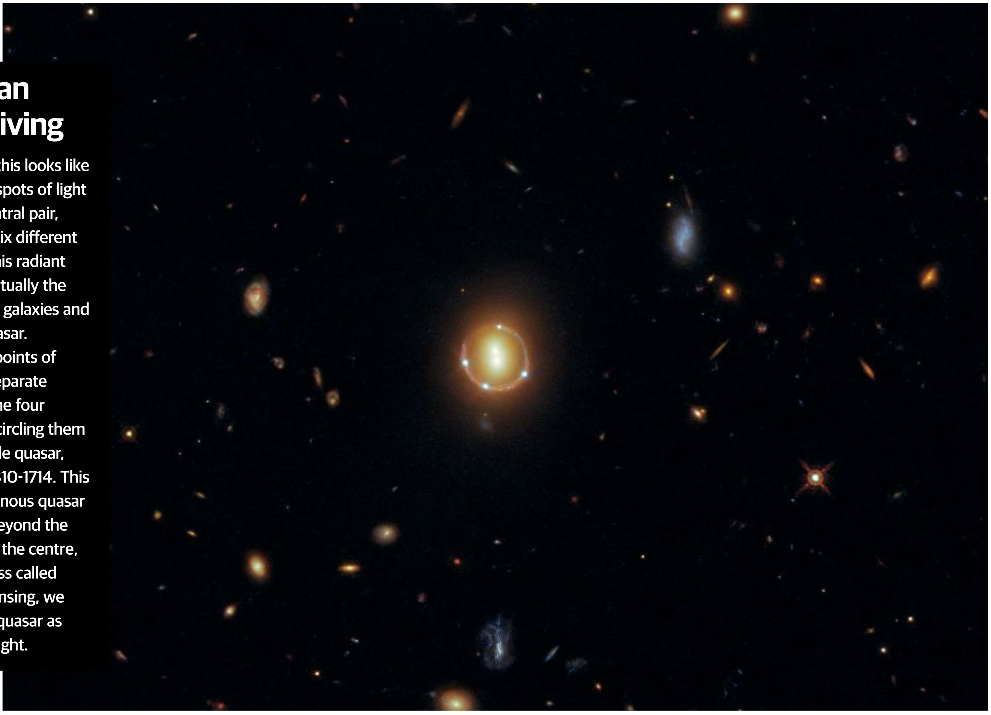
9 AUGUST 2021

Looks can be deceiving

At first glance this looks like four luminous spots of light encircling a central pair, perhaps from six different galaxies. But this radiant light show is actually the product of two galaxies and one distant quasar.

The central points of light are two separate galaxies, and the four points of light circling them are from a single quasar, known as 2M1310-1714. This extremely luminous quasar is located far beyond the two galaxies in the centre, but via a process called gravitational lensing, we see this single quasar as four points of light.



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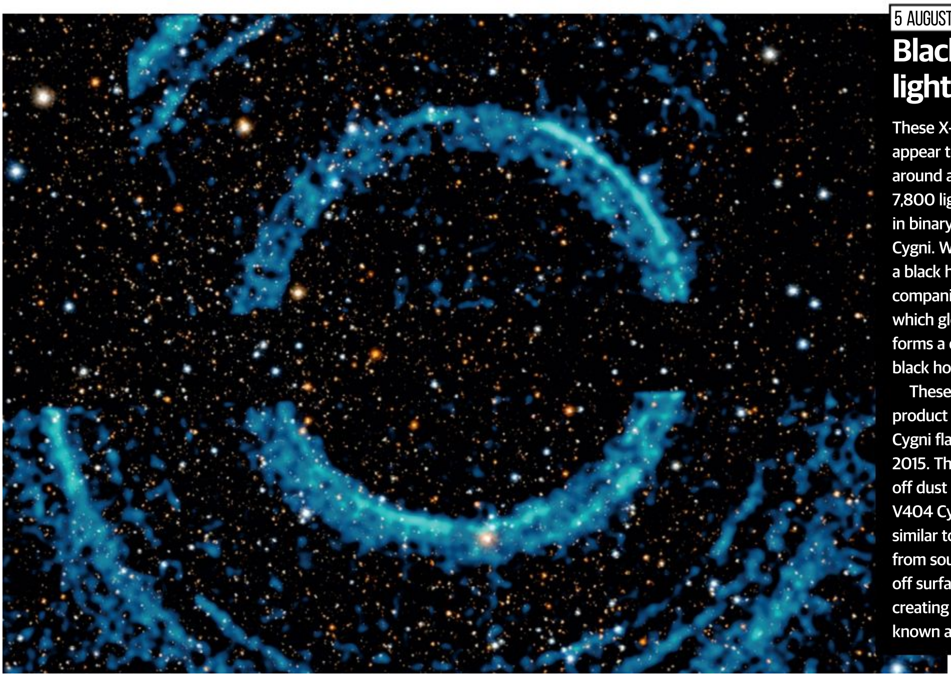
Black hole light echoes

These X-ray emissions appear to be running rings around a black hole located 7,800 light years away in binary system V404 Cygni. Within this system a black hole is stripping its companion star of material, which glows in X-rays and forms a disc around the black hole.

These rings are the product of X-rays from V404 Cygni flares observed in 2015. The X-rays ricocheted off dust clouds between V404 Cygni and Earth, similar to echoes created from sound waves bouncing off surfaces on Earth, creating a series of rings known as light echoes.



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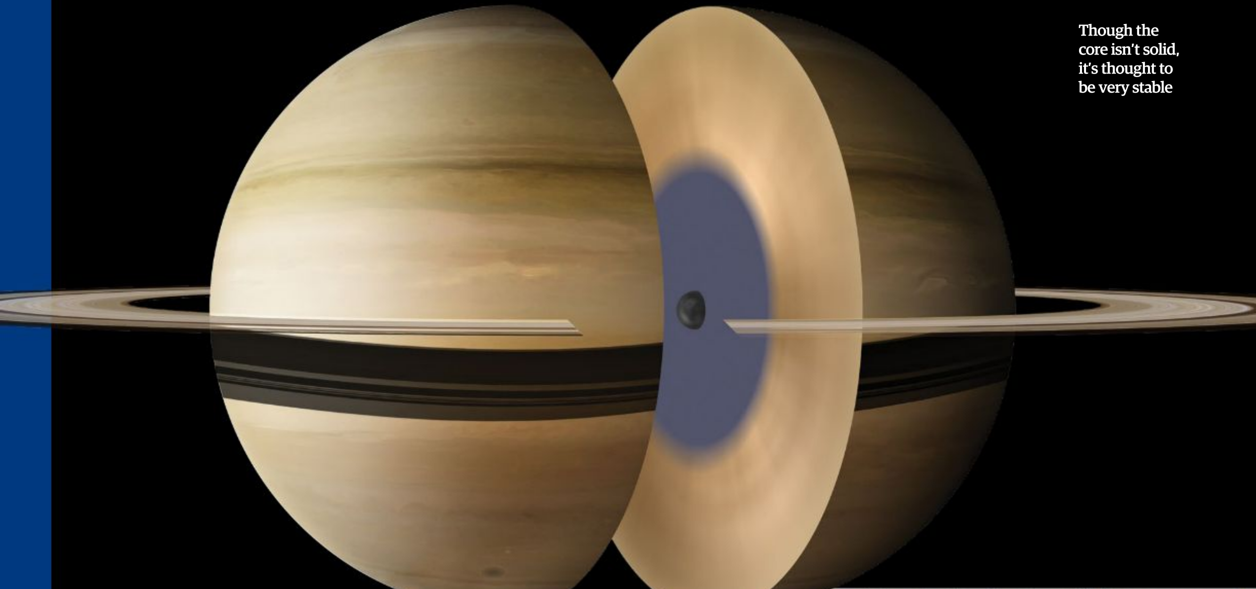

Though the core isn't solid, it's thought to be very stable

©Tobias Roetsch

SATURN'S RIPPLING RINGS POINT TO A MASSIVE, SOUPY CORE HIDDEN INSIDE

Words by Tereza Pultarova

Saturn's rings aren't just a beautiful adornment; scientists can use them to understand what's happening deep inside the planet. By using the famous rings like a seismograph, scientists studied processes in the planet's interior, determining that its core must be 'fuzzy'.

Instead of a solid sphere like Earth's, the core of Saturn appears to consist of a 'soup' of rocks, ice and metallic fluids that sloshes around and affects the planet's gravity. Scientists used data from NASA's Cassini mission, which orbited Saturn and its moons between 2004 and 2017.

In 2013, data from the mission revealed that Saturn's innermost ring, the D Ring, ripples and swirls in ways that cannot be entirely explained by the gravitational influences of the planet's moons. The researchers then looked at these motions in Saturn's rings in greater detail to gain insight into the processes in its interior.

"We used Saturn's rings like a giant seismograph to measure oscillations inside the planet," said Jim Fuller, an astrophysicist at the California Institute of Technology. "This is the first time we've been able to seismically probe the structure of a gas giant, and the results were pretty surprising." Not only does the planet's core seem sludgy, it also appears to extend across 60 per cent of the planet's diameter, making it much larger than previously estimated. The analysis showed that Saturn's core might be about 55 times as massive as the entire Earth. Of the total mass of the core, 17 Earth masses are made of ice and rock, with the rest consisting of a hydrogen and helium-based fluid.

Christopher Mankovich, a planetary scientist who works with Fuller, explained that the motions in the core cause Saturn's surface to constantly ripple. These surface waves create minuscule changes in the planet's gravity that subsequently affect the rings. "Saturn is always quaking, but it's subtle," said Mankovich. "The planet's surface moves about a metre [three feet] every one to two hours like a slowly rippling lake. Like a seismograph, the rings pick up the gravity disturbances, and the ring particles start to wiggle around."

According to the scientists, the nature of those ring ripples suggests that the core, despite its sloshing, is composed of stable layers of various densities. Heavier materials sit around the centre of the planet and don't mix with the lighter materials closer to the surface. "In order for the planet's gravitational field to be oscillating with these particular frequencies, the interior must be stable, and that's only possible if the fraction of ice and rock gradually increases as you go in towards the planet's centre," said Fuller.

Mankovich compared the material in the core to sludge, adding that the layered but liquid nature of the core is akin to the salinity of Earth's oceans, which increases with depth. "The hydrogen and helium gas in the planet gradually mix with more and more ice and rock as you move towards the planet's centre," he said.

THE MILKY WAY HAS A 'BROKEN' ARM THAT COULD REVEAL ITS GALACTIC HISTORY

Words by Elizabeth Howell

© NASA/JPL-Caltech

Left: The Sagittarius Arm was looked at in detail in a new study

Scientists have found a strange 'break' in the spiral arms of our Milky Way. The grouping of young stars and gassy regions is described by NASA's Jet Propulsion Laboratory (JPL) as looking like "a splinter poking out from a plank of wood" from the plane of the spiral Milky Way's arms.

Researchers found the feature using the infrared eyes of NASA's now-retired Spitzer Space Telescope and the European Space Agency's Gaia, which measures stellar distances and motions. The new study focused on a nearby region of one of the Milky Way's arms, the Sagittarius Arm, which is full of young stars that move in space at nearly the same velocity and direction. "A key property of spiral arms is how tightly they wind around a galaxy," said Michael Kuhn, an astrophysicist at the California Institute of Technology.

Kuhn added that earlier models of the Milky Way suggested the winding, measured by the 'pitch angle' compared to a perfect circle at zero degrees, hinted that Sagittarius had a pitch angle of roughly 12 degrees. The new observations show the pitch angle of Sagittarius is almost 60 degrees, but why is still unclear.

Because the newly discovered feature's stars were formed around the same time and zone, they likely were influenced by bigger changes happening in the Milky Way. Such changes include the gravity and shear associated with the galaxy's rotation.

SPACEX STARLINK SATELLITES RESPONSIBLE FOR OVER HALF OF CLOSE ENCOUNTERS IN ORBIT

Words by Tereza Pultarova

Operators of satellite constellations are constantly forced to move their satellites because of close encounters with other spacecraft and pieces of space junk. And thanks to SpaceX's Starlink satellites, the number of such dangerous approaches will only continue to grow. Starlink satellites alone are involved in about 1,600 close encounters between two spacecraft every week, according to Hugh Lewis, the head of the Astronautics Research Group at the University of Southampton. These encounters include situations where two spacecraft pass within a distance of one kilometre (0.6 miles) from each other.

Lewis, Europe's leading expert on space debris, makes regular estimates of the situation in orbit based on data from the SOCRATES (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space) database. This tool, managed by CelesTrak, provides information about satellite orbits and models their trajectories into the future to assess collision risks.

Lewis has seen a worrying trend in the data that reflects the fast deployment of Starlink. "I've looked at the data going back to May 2019 when Starlink was first launched to understand the burden of these megaconstellations," said Lewis. "The number of encounters picked up by the SOCRATES database has more than doubled, and now we are in a situation where Starlink accounts for half of all encounters."

Below: Space debris is a cascading problem

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HOW BIG IS A BLACK HOLE? HOW MESSILY IT 'EATS' MAY BE A CLUE

Words by Meghan Bartels

Scientists have long noticed flickering patterns in the brightness of accretion discs, rings of matter pulled in by black holes' gravity. But researchers weren't sure what caused the flickering. But by studying dozens of known supermassive black holes, a team of astrophysicists has determined that the flickering of an accretion disc relates to the mass of the black hole swathed inside it - and the scientists believe that the same technique also applies to much smaller objects as well.

"These results suggest that the processes driving the flickering during accretion are universal, whether the central object is a supermassive black hole or a much more lightweight white dwarf," said Yue Shen, an astronomer at the University of Illinois Urbana-Champaign.

To examine any connection between black hole size and the flickering light of the disc it feeds from, the scientists began by selecting 67 of these behemoths, each with a previously estimated mass between 10,000 and 10 billion times that of our Sun. Supermassive black holes are much larger than stellar black holes, which form from a single star exploding and have masses three to ten times that of our Sun.

When the data seemed to show a correlation, researchers decided to look at smaller objects with accretion discs as well: white dwarfs, which are the much smaller dense remnants of stars like our Sun that have exploded. The scientists hope that the same relationship will hold for objects with masses between these two classes.

Above: Accretion discs could be the clue to weighing black holes

A MALAYSIAN SATELLITE HAS DIED IN SPACE AND WILL MEET A COLD GRAVE

Words by Elizabeth Howell

A Malaysian satellite will settle into a graveyard orbit following a mysterious 'anomaly' that struck it down in space. The nearly 15-year-old MEASAT-3 communications satellite suffered an unexplained issue on 21 June, knocking out service for its customers. It was brought under ground control on 24 June, but hasn't been operational since.

With the satellite playing dead and a 'root cause' investigation still ongoing by MEASAT and satellite maker Boeing, MEASAT announced it has decided to proceed with a deorbit. "Further testing and recovery efforts found that the satellite could not re-enter service. The satellite will be deorbited in the following weeks," said MEASAT. Because of the satellite's previous altitude, that likely means a graveyard orbit, rather than destruction in Earth's atmosphere.

MEASAT-3 launched on 11 December 2006 from Baikonur Cosmodrome in Kazakhstan, the same launch centre where Soyuz spacecraft send crews to the International Space Station. The spacecraft served more than 100 countries in Asia, Eastern Europe, the Middle East and Africa. Satellite TV operator Astro was among the customers affected. Most customers were transferred to backup satellites by mid-July, but the satellite has been tumbling in its orbit since at least 1 July.

ExoAnalytic noted there was no debris around MEASAT-3 that hinted at an in-space collision that may have caused the service problem. The satellite also has no near-term collision risk with any other space object, ExoAnalytic said. The satellite may have run out of fuel earlier than expected in its geosynchronous orbit.

© Measat

Left: A replacement, called MEASAT-3d, is expected to be launched next year

Right: If the test proves successful, we might see a reduction in space debris in the near future

ROCKET LAB WILL LAUNCH A FINNISH CUBESAT THIS YEAR TO TEST SPACE JUNK CLEANUP TECH

Words by Mike Wall

Technology that could ease humanity's space junk problem is about to get an orbital test. A tiny cubesat called AuroraSat-1 will launch atop a Rocket Lab Electron booster in the fourth quarter of this year.

AuroraSat-1, which will be operated by Finnish company Aurora Propulsion Technologies, will take off from Rocket Lab's New Zealand site on the North Island's Mahia Peninsula. After deploying in low-Earth orbit the cubesat will demonstrate systems designed to help operators maintain control of small satellites and bring them down to Earth before they become space junk.

"The cubesat will validate the water-based propellant and mobility control of its resistojets that can assist cubesats with detumbling capabilities and propulsion-based attitude control," said representatives from Rocket Lab. Terms of the launch agreement were not disclosed, and no target date was given. However, Rocket Lab did say that four other Electron missions are ahead of AuroraSat-1 in the company's planned queue.

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A: Beetle **B:** Teapot **C:** Toucan

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NEW SEARCH FOR ALIEN LIFE

ASTRONOMERS HAVE LONG ASKED WHETHER OR NOT WE ARE ALONE, AND NOW WE'VE ENTERED AN EXCITING NEW ERA

Reported by Mike Wall and David Crookes

For thousands of years humans have speculated that the cosmos is teeming with planets, many of which could support life. Our questioning has tapped into a long-held desire to know our place in the universe – a core human yearning which has preoccupied some of history's greatest minds. But speculation is about as far as humans got until we invented telescopes and developed a proper understanding of the scientific method a few centuries ago. Now scientists are making considerable progress in the search for alien life, and the past decade has proven pivotal. Some big discoveries may be coming soon, but where has the hunt for life taken us, and where is it heading?

One of the first modern searches for life took place in August 1924, when astronomer David Peck Todd and an inventor called Charles Jenkins wanted to listen for messages from Mars. They asked the US Army and Navy to turn off their stations so they could use their radio-photo message machine to carry out a search. Alas, they drew a blank. In 1960, however, the search for extraterrestrial intelligence (SETI) intensified when Cornell University astronomer Frank Drake used a radio telescope in West Virginia to listen for interstellar radio waves coming from the stars Tau Ceti and Epsilon Eridani. Called Project Ozma, this effort incorporated ideas from a seminal 1959 paper by Giuseppe Cocconi and Philip Morrison. But again it detected no recognisable signals.

Undeterred, scientists have been scanning the heavens for technosignatures ever since. Initially they focused almost exclusively on radio signals, but flashes of light are now being sought too. These are the targets of increasingly common 'optical SETI' efforts. But then SETI scientists have to keep an open mind. After all, we don't know what sorts of messages advanced alien civilisations might beam out. It means astronomers in the field are generally looking for signals that appear weird and artificial. They search for something coming from deep space that isn't produced by any known natural astrophysical phenomenon.

An identified signal would ideally recur so it can be studied repeatedly and in detail. One-offs can remain forever mysterious, as 1977's famous Wow! signal shows. In that case, a radio dish operated by Ohio State University picked up something so intriguing that astronomer Jerry Ehman wrote 'Wow!' on the data printout. Researchers scoured that same patch of sky again and again, hoping to get another ping, but they never did.

What's perhaps more frustrating is that SETI has historically been a shoestring operation, and finding enough money to keep the telescopes running has been a consistent problem. US Congress axed a planned NASA-SETI project in 1993, with Senator Richard Bryan saying: "This hopefully will be the end of Martian hunting season at the taxpayer's expense."

ET hunters have mostly had to turn to the private sector for cash, and without steady funding, progress became slow for several years. Things changed recently when private money began to flow more freely into SETI research. Most of it comes from one man – tech billionaire Yuri Milner – but his passion for the search for alien life prompted him to establish an ambitious program called Breakthrough Initiatives in 2015.

Projects under the Breakthrough umbrella include the $100 million (£73 million) Breakthrough Listen SETI campaign and the $100 million (£73 million) Breakthrough Starshot, which aims to develop the technology required to send tiny robotic probes to nearby exoplanet systems at about 20 per cent the speed of light. There's also Breakthrough Message, which aims to help humanity craft the best possible message to send out into the cosmos and encourages debate and conversation about SETI in general.

Even so, there is considerable debate within the scientific community about SETI. Some people, including the late physicist Stephen Hawking, have argued that it's unwise to advertise our presence to aliens, whose nature and intent are complete mysteries to us. "We should be wary of answering back," he said. "Meeting an advanced civilisation could be like Native Americans encountering Columbus. That didn't turn out so well."

Other researchers think that any creatures advanced enough to travel to Earth to enslave or eat us would already know we're here. Just to be on the safe side, Breakthrough Message pledges not to actually broadcast any SETI signals until this

Right: Hollywood has long tapped into our fascination with alien life, as 1982's *E.T. the Extra-Terrestrial* shows

© Getty

© GMTO Corporation/M3 Engineering; Getty

debate has played itself out – though humanity has already beamed out messages on multiple occasions, most famously in 1974 with the Arecibo message. Humanity is also leaking radio signals in all directions at all times, providing cosmic bread crumbs for anyone close enough to find them. Around the same time that SETI was getting off the ground, planetary scientists began getting their first good look at alien worlds.

In 1965, Mariner 4 flew by Mars, returning the first close-up images of the Red Planet. Those photos revealed a dry, heavily cratered and seemingly desolate world, forcing many scientists to recalibrate previously optimistic notions of Mars' habitability. Hopes of a life-supporting Mars had been famously stoked around the turn of the 19th century by astronomer Percival Lowell, who claimed that channels on the planet were actually canals built by intelligent creatures.

But the optimists got some good news in 1971 after Mariner 9 arrived in orbit around Mars, becoming the first spacecraft to circle another planet. This intrepid probe spotted river channels and other evidence of past liquid-water activity on the Martian surface. These discoveries helped spur NASA to develop two ambitious life-hunting Mars missions, Viking 1 and 2, which launched a few weeks apart in 1975.

The twin Viking landers each carried four biology experiments which hunted for signs of microbial life in the red dirt. One of those, called the Labeled Release (LR) experiment, returned data consistent with evidence of microbial life. Indeed, LR principal investigator Gil Levin argued that the Vikings found evidence of Mars life. However, most scientists who studied the data disagreed with Levin, determining that the data could be explained by abiotic chemical reactions.

The Viking results taught NASA some valuable lessons – chiefly that we didn't know enough about Mars to mount a proper life hunt there. The space agency eventually embarked on a long-term 'follow the water' exploration strategy, seeking to learn more about ancient environmental conditions on the Red Planet and how they changed over time.

This strategy gave us many prominent Mars missions over the past few decades, including Mars Odyssey, the Mars Reconnaissance Orbiter, Mars Atmosphere and Volatile Evolution (MAVEN), the rovers Spirit, Opportunity, Curiosity and Perseverance and the Phoenix lander. These robotic explorers did their jobs well, finding lots of evidence that ancient Mars was quite wet, and helping scientists better understand why, how and when the Red Planet transitioned to the frigid desert world it is today. Curiosity has taken this work the furthest, finding that its landing site, the 154-kilometre (96-mile) Gale crater, hosted a long-lived lake-and-stream system billions of years ago that could have supported Earth-like life.

Meanwhile, other scientists have continued the hunt for Mars life, focusing on aliens that may have fallen fortuitously to Earth. Billions of Red Planet rocks have made their way here from Mars after being blasted into space by powerful asteroid or comet impacts. A lot of Earth material has ended up on Mars as well, but the ledger is decidedly unbalanced – the Sun's powerful gravity pulls more stuff inward, towards Earth. This extensive rock-swapping has led some scientists to postulate that life actually arose first on Mars, then made its way to Earth later.

In 1996 researchers announced they'd found potential signs of life in one such Mars meteorite, known as Allan Hills 84001 (ALH84001). It was a very big deal. The result was published in the prestigious journal *Science*, and President Bill Clinton held a press conference about the news on the White House lawn. But the ALH84001

Below: This stained-glass window depicts the Arecibo transmission, an interstellar radio message broadcast into space in 1974 by Frank Drake

© Getty

EXPLORING THE UNIVERSE WITH THE GIANT MAGELLAN TELESCOPE

Ten times more powerful than Hubble, this ground-based observatory is due to become operational in 2029

1 SECONDARY MIRRORS

Light reflected from the primary mirrors will reflect off seven smaller mirrors, each of which is flexible. Beneath them lie hundreds of actuators that adapt the optics to compensate for atmospheric distortion, allowing for sharper images.

2 THE CENTRAL HOLE

Light from the secondary mirrors is reflected down through a hole in the central primary mirror, where the concentrated light can be measured by advanced scientific instruments.

3 TELESCOPE MOUNT

Beneath the telescope is a mount, standing 36 metres (118 feet) above the observing floor. It holds the secondary-mirror support system and moves on two near-frictionless bearings.

4 THE DOME

The 22-storey enclosure, built in the Atacama Desert in Chile because it's one of the highest, driest locations on Earth, has retractable doors that can be opened at night.

5 SCIENTIFIC INSTRUMENTS

Beneath the primary mirrors are CCD imaging cameras and spectrographs which not only capture, but record the collected light, determining how far away objects are and what they are made of.

6 PRIMARY MIRRORS

Seven stiff monolith mirrors – each 8.4 metres (27 feet) in diameter – collect light from distant objects. They are shaped and polished within a wavelength of light, and together they form an optical surface that is 24.5 metres (80 feet) in diameter.

story ended up going down a Viking path. Other scientists picked at the claim, and a consensus emerged that the meteorite evidence was ambiguous at best. But like Levin, the team held firm in its findings, and continues to do so today.

NASA and the broader exploration community weren't focused solely on Mars for all these years, however. The Cassini-Huygens mission, which ended in September 2017, transformed scientists' understanding of the Saturn system and our Solar System's potential to host alien life. That mission found that Titan, Saturn's largest moon, has a hydrocarbon-based weather system and that the frigid moon's surface harbours lakes and seas of liquid ethane and methane. Life could swim around in these seas, though it would have to be very different from the life we know here on Earth.

Cassini also spotted geysers blasting from the south pole of another Saturn moon, the ice-covered

Right: Viking 1 was sent to Mars in 1975, becoming the first lander to trundle along the surface of the Red Planet

© NASA

> "MEETING AN ADVANCED CIVILISATION COULD BE LIKE NATIVE AMERICANS ENCOUNTERING COLUMBUS"
>
> STEPHEN HAWKING

AR SCAN HERE

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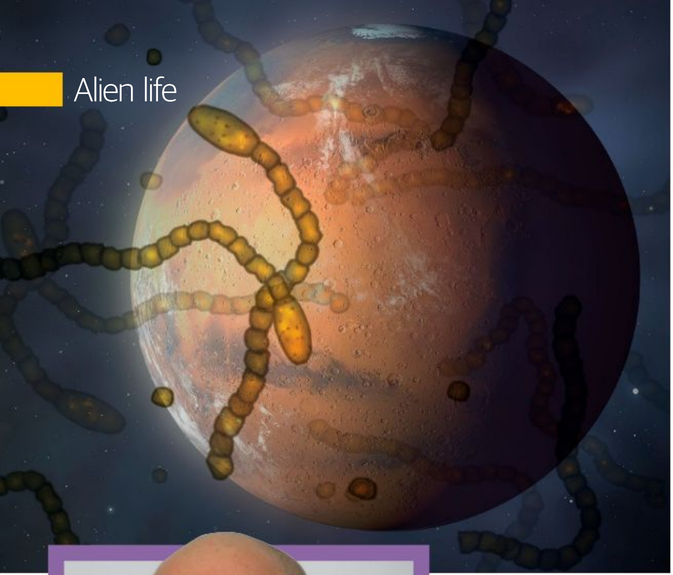
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Left: If life does exist on other planets, it may not be anything more advanced than microorganisms

Below: Russian-Israeli entrepreneur Yuri Milner launched Breakthrough Initiatives in July 2015 to investigate the possibility of life in the universe

© Getty

Enceladus. This discovery, among other Cassini observations, revealed that Enceladus harbours a big ocean of salty liquid water beneath its shell.

These geysers blast up huge plumes of water ice and other material in clouds so substantial that they create Saturn's E ring. Cassini flew through one such plume on multiple occasions, gathering samples that scientists analysed for clues about the moon's subsurface environment.

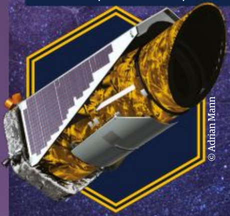
The researchers found carbon-containing organic compounds and free hydrogen, the latter of which suggests the existence of a hydrothermal system in Enceladus' buried ocean. Undersea hydrothermal vents are one popularly invoked environment for the origin of life on Earth. But Cassini didn't look for signs of life in plume material; the spacecraft wasn't equipped to do so because nobody knew about the plumes before the mission launched. Now scientists have come to realise that buried oceans are relatively common in the outer Solar System. "There are more oceans in the universe than previously thought, making the existence of extraterrestrial life more plausible," says Shunichi Kamata of Hokkaido University in Japan.

Multiple ice-covered Jupiter moons seem to have these oceans: Ganymede, Callisto and, most intriguingly, Europa. Europa's huge subsurface sea seems to be in contact with the moon's rocky core, like the ocean of Enceladus is, making possible a range of complex chemical reactions that could theoretically have led to life. Scientists think the oceans of Ganymede and Callisto are more boring, sandwiched between layers of ice. Titan seems to have a buried ocean of salty water as well, meaning the moon likely has two very different potentially habitable environments. Observations by NASA's New Horizons spacecraft indicate that liquid water may slosh beneath Pluto's surface, too.

And the list goes on. The abundance of water worlds in the outer Solar System suggests that looking for 'Earth 2.0' may not be the best life-hunting strategy after all – most of the habitable real estate in the cosmos may be buried under ice. And these revelations about our celestial backyard have come in parallel with big news about the cosmos at large.

GOING EQUIPPED IN THE HUNT FOR ET

Telescopes and spacecraft are helping astronomers look for vital signs of life across the universe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KEPLER SPACE TELESCOPE

2009 to 2018

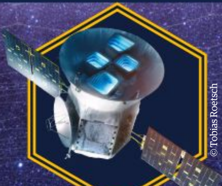
Searching for over nine years, Kepler enabled scientists to observe 530,506 stars and 2,662 planets from outside our Solar System. It showed that between 20 and 50 per cent of stars have planets similar in size to Earth within their habitable zone – that's a lot of potential for life.

© Getty

FIVE-HUNDRED-METER APERTURE SPHERICAL TELESCOPE

2016 to present

FAST uses radio waves to locate exoplanets, seeking to detect electromagnetic transmissions of artificial origin. If aliens are trying to contact us, this telescope could pick up the call!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TESS EXOPLANET-HUNTING MISSION

2018 to present

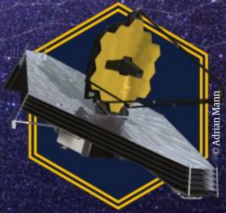
The Transiting Exoplanet Survey Satellite has discovered thousands of exoplanets orbiting dwarf stars. It has enabled astronomers to build a vast database of worlds that are close enough to be studied for signs of extraterrestrial life.

© Adrian Mann

MARS 2020

2020 to present

Part of NASA's Mars Exploration Program, Mars 2020 is the mission which has placed the Perseverance rover on the surface of Mars. It has also launched a rotary helicopter called Ingenuity. Their primary aim is to seek signs of ancient life.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JAMES WEBB SPACE TELESCOPE

2021 to 2031

The successor to Hubble will peer back 13.5 billion years to the time when the first stars and galaxies were formed. Able to detect infrared, it will be able to determine the atmospheres of planets and detect if they are being modified by alien life.

Over the past decade or so, we've learned that our Milky Way galaxy is teeming with potentially life-supporting worlds. Much of this knowledge comes courtesy of NASA's pioneering Kepler space telescope, which operated from 2009 through to November 2018. Kepler is responsible for nearly two-thirds of the 4,400 confirmed exoplanet discoveries to date, and mission data reveals that planets outnumber stars in our galaxy. Many of those planets might bear more than a passing resemblance to Earth. Kepler found that at least 20 per cent of Milky Way stars probably host rocky planets in their habitable zones, the just-right range of orbital distances where liquid water can persist on a world's surface.

Some of these potentially habitable worlds are just a stone's throw away in the cosmic scheme of things. For example, the nearest star to the Sun – Proxima Centauri, which is about 4.2 light years away from us – hosts a roughly Earth-sized planet in the habitable zone. This world, called Proxima b, is a prime Breakthrough Starshot target. And the TRAPPIST-1 system, which lies 39 light years from us, boasts seven rocky worlds, three of which may be capable of supporting life as we know it. But both Proxima Centauri and TRAPPIST-1 are red dwarfs, like 70 per cent of the Milky Way's stellar population. Red dwarfs are small but very active stars, and their intense flaring may severely dampen planets' habitability.

Kepler's legacy is being carried on by other exoplanet missions, such as NASA's Transiting Exoplanet Survey Satellite (TESS), which is expected to find thousands of alien worlds circling nearby stars, and the European Space Agency's (ESA) CHEOPS (CHaracterising ExOPlanet Satellite), which aims to characterise some of these neighbouring worlds. The avalanche of exoplanet discoveries, as well as finds much closer to home, have brought astrobiology from the scientific fringe firmly into the mainstream. NASA is openly prioritising the search for alien life these days, as some current and coming missions show.

In July 2020 the space agency launched the Perseverance rover, which landed in February 2021 to hunt for signs of ancient Mars life and collect samples for eventual return to Earth. Finding evidence of long-dead microbes is expected to be a very tricky task, one ideally carried out by teams of scientists in well-equipped labs studying pristine pieces of Mars specifically selected for their life-preserving potential. The ESA planned to launch its own life-hunting Mars rover, called Rosalind Franklin, in July 2020 as well, but technical issues pushed the launch back to the next window – it's now scheduled for autumn 2022.

In 2024 NASA's Europa Clipper is scheduled to launch towards the Jupiter system. Clipper will orbit the gas giant but make dozens of flybys of Europa, characterising the moon's subsurface ocean and scouting out good touchdown sites for a future life-hunting lander, among other tasks. And in 2027 NASA plans to launch Dragonfly, a probe that will fly through Titan's thick, smoggy

Right: This illustration of Titan shows what looks like water on the surface. It's actually liquid hydrocarbons, and could indicate life

TAP HERE TO PLAY

© Getty

© NASA

EUROPA CLIPPER

2024 to 2034

This mission plans to send an orbiter to perform as many as 50 flybys of Jupiter's icy moon Europa. By scanning close to every part of the moon, NASA hopes to use cameras, spectrometers and ice-penetrating radar to work out if Europa is capable of hosting life.

© Adrian Mann

DRAGONFLY

2027 to 2039

Planning to launch in six years, a robotic rotorcraft will be sent to the surface of Saturn's largest moon Titan. After landing in 2034 it will search for the building blocks of life. It's going to take its scientific payload to multiple locations, which will give astronomers an abundance of data.

© TMT Observatory Corporation

THIRTY METER TELESCOPE

2027 onwards

When it's built – high atop a volcano in Hawaii – this telescope will be one of the most powerful ever seen. Scientists are also identifying planets it could help them study for signs of life, including Proxima Centauri b.

© ESO

EXTREMELY LARGE TELESCOPE

2027 onwards

Part of the European Southern Observatory, this telescope is being built in the Atacama Desert in Chile, and will be used to scan the skies for exoplanets. It will have 250 times the light-gathering area of Hubble and produce images that are 16 times sharper.

© GMTO Corporation/M3 Engineering

GIANT MAGELLAN TELESCOPE

2029 onwards

This telescope will produce direct images of planets in the habitable zones of other stars. Astronomers will be able to analyse the atmospheres of those exoplanets and look for key indicators of life, potentially making some staggering breakthroughs.

LIFE WITHIN THE SOLAR SYSTEM?

Earth is the only planet we know of that hosts life, but which other worlds could one day surprise us?

TAP HERE TO PLAY

VENUS

Type of world: Planet

Minimum distance from Earth: 225 million kilometres (139 million miles)

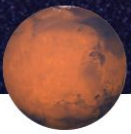
Venus is the hottest planet in our Solar System, so that should rule out the potential for life. But there is a theory that microbes could exist in the clouds, where temperatures are cooler. In fact, phosphine – a potential marker of life – has been observed in the clouds.

MARS

Type of world: Planet

Minimum distance from Earth: 225 million kilometres (139 million miles)

Mars has long been seen as a prime candidate for harbouring life because of its proximity and similarity to Earth. In reality the surface of Mars is unlikely to be hospitable to life today, but microorganisms could exist in ice or water within the planet's subsurface.



EUROPA

Type of world: Moon

Minimum distance from Earth: 780 million kilometres (485 million miles)

Cracks on the surface of Europa, one of Jupiter's moons, as well as fluctuations in its magnetic field, have led scientists to believe there is a vast ocean beneath the surface. There is a possibility that it could contain some form of life, if not in the water itself then in the upper ice layers.

ENCELADUS

Type of world: Moon

Minimum distance from Earth: 1.272 billion kilometres (745 million miles)

Scientists believe that Saturn's sixth-largest moon has the ingredients needed for life. Aside from a global ocean beneath its icy crust, hydrogen was discovered in the plumes erupting from the south pole, meaning there's a source of chemical energy. It's our greatest hope for a discovery.

CERES

Type of world: Dwarf planet

Minimum distance from Earth: 426 million kilometres (265 million miles)

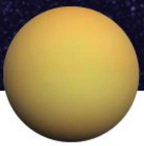
Ceres, the largest object in the asteroid belt, has water, and it could be in liquid form, so there is a ferocious appetite to explore this celestial body further. If life is discovered it's not likely to be anything more than small microbes, but that would nonetheless represent a major breakthrough.

TITAN

Type of world: Moon

Minimum distance from Earth: 1.6 billion kilometres (1 billion miles)

Saturn's hazy moon has a subsurface ocean of liquid water. It also has lakes and rivers of liquid methane and ethane, as well as a weather system similar to Earth's. Astronomers ponder how methane is finding its way into the atmosphere. If life exists, however, it may not be quite as we know it.



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skies. Dragonfly's main goals involve investigating the complex chemistry that could set the stage for life's emergence and assessing Titan's habitability, but the rotorcraft will also search for biosignatures.

The agency will soon start hunting for aliens much farther afield, too. NASA's $9.7 billion (£7.1 billion) James Webb Space Telescope, the oft-delayed successor to the iconic Hubble Space Telescope, is scheduled to launch in November 2021. One of the many things the powerful new telescope will do once aloft is probe the atmospheres of nearby exoplanets for potential biosignatures – gases such as oxygen and methane, whose simultaneous presence in a world's air would provide a strong case for life.

Three highly anticipated megascopes will begin doing similar work from the ground in the next decade if all goes according to plan. The Giant Magellan Telescope (GMT) and the Extremely Large Telescope (ELT) will do their observing from the mountains of Chile, whereas the Thirty Meter Telescope (TMT) will sit atop Hawaii's Mauna Kea volcano – if the telescope team and the local community can come to an agreement.

Left: What would it be like to stand on one of the seven Earth-sized planets orbiting the TRAPPIST-1 star – one of which may support life?

© Getty

SETI activities may ramp up considerably soon, too, and not just because of Breakthrough Listen. The biggest radio telescope ever built, China's Five-hundred-meter Aperture Spherical Telescope (FAST), nicknamed Tianyan, came fully online in early 2020, and searching for technosignatures is one of its many charges.

This is just a partial list of the coming life-hunting activities and technologies. The full list may eventually become gloriously ungainly thanks to the continuing drop in the cost of building and launching spacecraft. This trend could eventually make astrobiology missions feasible for a variety of interested parties, from university groups to private citizens. Indeed, Milner has already mused about launching a life-hunting mission to Enceladus or Europa.

Some of this alien searching will continue to occur in Earth-based studies, and it won't just involve inspection of Mars meteorites. There's an ongoing search for a 'shadow biosphere' on our planet – an entire tree of life separate from the one that includes bacteria, bats, birds and everything else we currently recognise as alive.

This peculiar pursuit isn't so crazy if you think about it. After all, life appeared on Earth about 4 billion years ago – very quickly considering that our planet formed just 4.5 billion years ago and remained hot and inhospitable for a long time thereafter. Life's emergence really doesn't seem that miraculous, which in turn implies that it could have happened here more than once. Given the incredible abundance of potentially habitable real estate – and that's just for Earth-like life, saying nothing of the environments that could support 'strange life' of various types – why haven't we found extraterrestrials yet?

Nobel Prize-winning physicist Enrico Fermi famously posed this question in 1950, specifically referring to intelligent aliens. Seven decades later, the answer to the so-called Fermi paradox remains elusive. 'Answers' is probably a better formulation, however, because multiple factors are most likely working together to keep us from finding intelligent aliens. Among the foremost is the vastness of space, which makes it difficult for two civilisations to touch base. Consider that Proxima b is just 4.2 light years away in a galaxy 100,000 light years wide. But 4.2 light years is an expanse that would take humanity's current spacecraft tens of thousands of years to cross.

Contact with intelligent aliens would require temporal and temperamental alignments as well: their civilisation would have to rise in sync with ours, no mean feat in a universe that's 13.8 billion years old. And ET would have to want to reach out – that's no given, either. There are many reasons why some aliens may want to keep quiet, as the pessimists have pointed out. Or maybe intelligence is rare throughout the cosmos, even if life isn't. Planet Earth has been inhabited for about 4 billion years, after all, but we've only been sending out radio waves for just a century or so and launching spacecraft since 1957. And it's very tough to find faraway microbes, which presumably have not yet invented the radio.

Our technological youth may be the biggest factor of all: we've only just begun the search for our cosmic neighbours. And that search has been halting and haphazard, conducted by small teams of dedicated researchers who have had to scrounge money to keep the lights on. But that's changing, as the exciting new missions and instruments currently in development show. We may start getting some answers very soon.

Mike Wall
Space.com Senior Space Writer
Mike joined **space.com** in 2010 as a senior writer. He has also worked as a herpetologist and wildlife biologist and holds a PhD in evolutionary biology.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

SEARCHING FOR LIFE ON MARS

Sarah Stewart Johnson, a planetary scientist at Georgetown University, has written a book, *The Sirens of Mars*, in which she explores science's attempts to discover life on Mars

© Brittany Waddell

Why did you want to write this particular book about Mars?
The book is about the search for life on Mars, but it's not just the science of it; it's about our human relationship to the planet as well. There were just so many things that were poignant and beautiful and compelling about the endeavour that will never really find expression in the pages of scientific journals. That's a large part of why I decided to write the book: this idea that Mars deserved a different type of treatment, something that captured the mystery and the wonder, and just of the entire quest.

Why is looking for life on Mars a valuable endeavour?
Even the discovery of simple life beyond Earth really stands to make a tremendous impact. We've had these massive advances over the last decades, but biology is still this rather descriptive science. It's because we have this one data point – we've got life on Earth, and we don't have a second data point. If we found evidence of a second genesis [a case where life arose independently of life found on Earth, rather than migrating between the two worlds], I think it'd be as revolutionary as any breakthrough that's been made in terms of thinking about ourselves and our existence.

Do you think it's possible we'll hit the point at which scientists can confidently say there is no life on Mars?
It's certainly possible there is no life on Mars, that we'll search and search and, like the Moon, we conclude pretty conclusively that that's it. Who knows what we'll find, but that's one of the great things about Mars. It's accessible, and we have developed so many tools and techniques where we can really do such good science on the planet. We can get there quickly and we can deploy really capable robots to do tremendously sophisticated science on the surface

If there is no life on Mars, what happens next?
Fortunately, there are lots of other targets – even in our own Solar System – that are really exciting to think about. All these other astrobiological destinations, like Enceladus and Europa, and Titan's a place that we're really excited about in my laboratory. A lot of our work is trying to imagine life as we don't know it and how we might detect life forms that are almost inconceivable within the confines of current thinking.

Below: Could our fleet of missions uncover life on the Red Planet?

© NASA/JPL-Caltech

AR SCAN HERE

© Jay Wong; Alamy

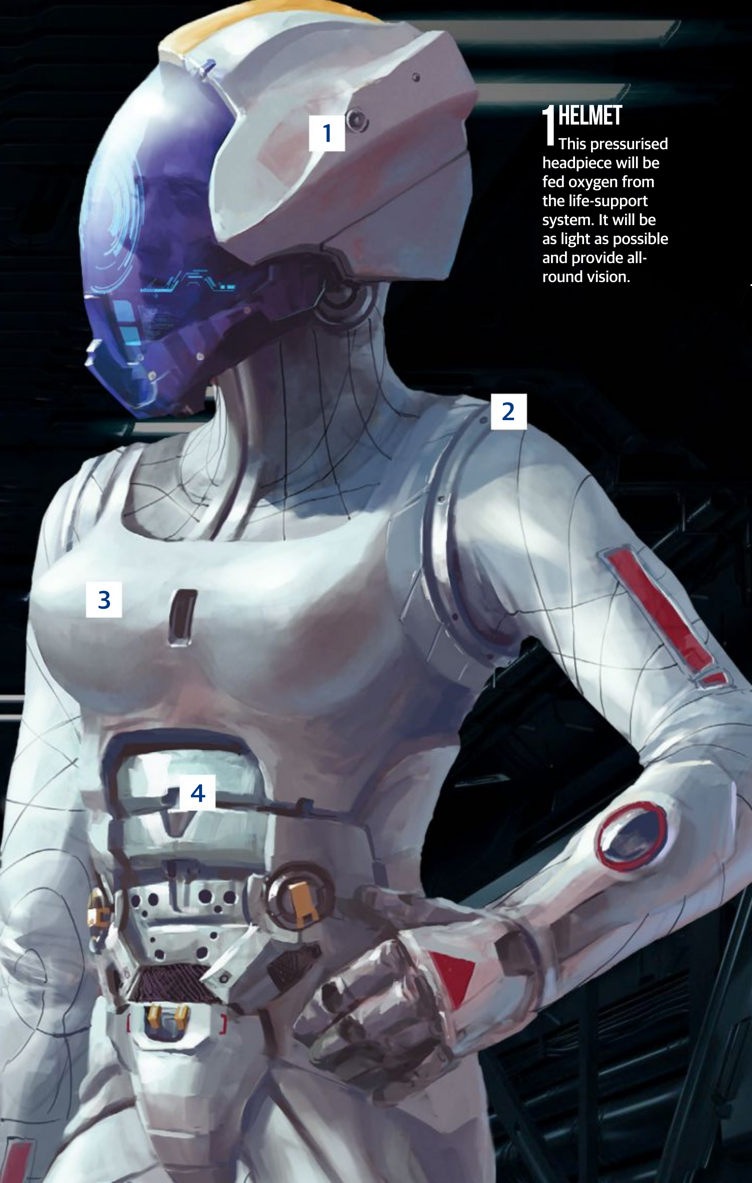
FLEXIBLE SPACESUITS

The new BioSuit would be tailor-made for each individual astronaut, making it a perfect fit

Contemporary spacesuits are not for the fashion-conscious. Bulky, heavy and inflexible, they nonetheless provide a vital role in keeping astronauts safe from the punishing forces experienced in space and on the Moon. Fortunately, a team has been working towards creating a spacesuit that will provide a better range of flexibility and comfort for future generations. Current spacesuits have 14 layers, all of which provide roles such as cooling the astronaut and insulating them, as well as avoiding tears and shaping. All of this adds up to make a suit weigh over 100 kilograms – although this doesn't affect astronauts so much when in space due to the lack of gravity.

But a new suit being designed by a team from the Massachusetts Institute of Technology (MIT) will have a form-fitting elastic layer, providing counter-pressure to the astronaut by wrapping them tightly in the suit. This essentially shrink-wraps them to ensure that no foreign bodies or radiation can get onto the astronaut's skin. This will replace the bulky pressurised gas systems that are being used by current spacesuits. The suits used currently come in a one-size-fits-all format, but the new BioSuit will be as individual as it's possible to get, with each astronaut having 3D laser scans taken of their body to create the tightest fitting suit possible.

The main layer of protection will come in the form of a rigid shell suit that will be clipped to the suit. This should be enough to protect



1 HELMET This pressurised headpiece will be fed oxygen from the life-support system. It will be as light as possible and provide all-round vision.

2 ENERGY EFFICIENT The BioSuit could effectively be shrink-wrapped onto the body, making it extremely cheap and efficient to use.

3 OUTER SHELL This firm structure is clipped to the BioSuit to protect the body against flying debris or even knocks against the spacecraft.

4 LIFE-SUPPORT SYSTEM This is strapped to the hard outer shell of the suit system in order to provide oxygen and pressurised gas to the astronaut.

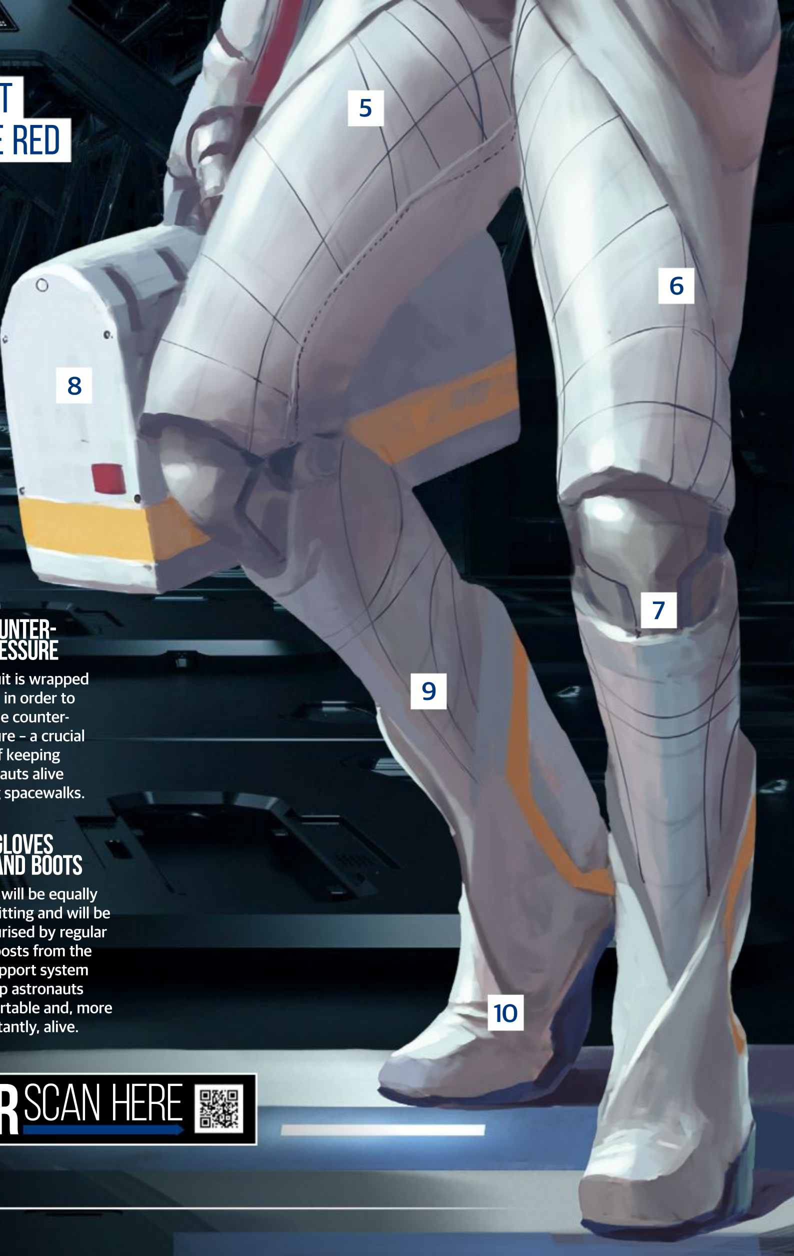
“THIS COULD WELL BE THE SPACESUIT THAT THE FIRST ASTRONAUT ON THE RED PLANET WILL BE WEARING”

spacewalkers from small pieces of debris. The life-support system is attached to the shell, providing oxygen to the astronaut via the helmet as usual. The life-support system will also be used to provide additional pressure to the arms and legs. By removing layers of protection and insulation, astronauts will have a vastly improved range of movement, making it much easier to repair things in space or perform other tasks that would previously have been hampered by decreased mobility.

A further hope for the suit is that it will work in harmony with the human body and, much like a sports compression shirt, induce a pressure on the body to mimic the effects of Earth's gravity. This would be extremely useful to astronauts, who often experience bone loss and find their muscles to be weakened after returning from long space voyages.

Even though the primary aim of the BioSuit is for it to be lightweight and flexible, the vastly reduced bulk could enable extras to be added to it - like communication systems and sensors - so that scientists back on Earth can get an even better idea of what pressures the human body undergoes when in outer space.

Estimates suggest that we are still a few years away from a fully operational BioSuit, but the potential for a lightweight, flexible suit is an exciting prospect. It's a future technology that NASA clearly agrees with, as its NASA Innovative Advanced Concepts (NIAC) arm has provided funding to the project. A second-skin spacesuit like this would greatly enhance the capacity of astronauts to take on projects in space that are currently too intricate or risky using current technology. The suit's suitability for dusty environments could also make it an ideal option for working on Mars. Who knows, this could well be the spacesuit that the first astronaut on the Red Planet will be wearing the day they make that historic first step.



9 COUNTER-PRESSURE

The suit is wrapped tightly in order to provide counter-pressure – a crucial part of keeping astronauts alive during spacewalks.

10 GLOVES AND BOOTS

These will be equally tight-fitting and will be pressurised by regular gas boosts from the life-support system to keep astronauts comfortable and, more importantly, alive.

AR SCAN HERE

5 FITTED SUIT

3D laser scans will be taken of an astronaut's body so the team can create a personalised suit that fits without any depressurising gaps.

6 LIGHTWEIGHT

The suit is designed to be as light as possible, making spacewalks a much more comfortable experience and enabling trickier tasks to be carried out.

7 EXTRA SKIN

The tight-fitting nature of the suit will improve muscular performance and endurance, as well as blood circulation.

8 ADDED EXTRAS

The BioSuit would enable scientists to add extra technologies which are impractical on current spacesuits due to their weight and bulk.

INTERVIEW

BIO

Major Tim Peake

Peake became the European Space Agency's (ESA) first British astronaut after launching into space on board a Soyuz rocket in December 2015. He returned to Earth on 18 June 2016, spending a total of 186 days in orbit as part of Principia on Expedition 46 and 47. He is a British Army Air Corps officer, previously serving in the military as a platoon commander, lieutenant and captain, a qualified helicopter pilot and instructor.

© Getty

MAJOR TIM PEAKE

“IT IS STARTLINGLY CLEAR THAT THERE IS NO PLANET B”

The ESA's first British astronaut reveals how space travel will develop, what life is like on board the ISS and why we need to protect our planet

Interviewed by Ailsa Harvey

What is life like living aboard the International Space Station (ISS)?

As astronauts, we're constantly pushing the boundaries of what's possible. And that includes life on board the International Space Station, using it as a platform for innovation and technology. On board the space station, we have virtual-reality systems where we can actually prepare to do a spacewalk, for example, doing it multiple times before actually going outside the space station. We've also got augmented reality, where Mission Control has come on board the space station, and it helps us in our day-to-day tasks as well.

All of this is absolutely essential in giving us astronauts greater confidence in what we're doing, especially when we have complex tasks coming up, and helping to ensure mission success. When it comes to spacewalking, probably an astronaut's greatest fear is going tumbling off into the black abyss of space. Anybody who's watched the opening scenes of the movie *Gravity* will have an idea of what that might be like – something that we are obviously quite concerned about in space.

But it's not something that we put to the back of our minds. We really confront every risk that we might encounter. We try to mitigate those risks as much as possible, and in terms of spacewalking, if we were to become detached from the space station then we actually have a number of ways of trying to stop that from happening, from tethers to putting down a small steel cable that keeps us anchored to the space station if all of that should break. And there's a small jet pack. It gives us about 20 seconds worth of nitrogen propellant – just enough to stop us from tumbling. To try and reorientate ourselves to find the space station or give us that one-shot chance of making it back raises the question of how you train for flying a jet pack down here on planet Earth. It's quite a tricky thing to do.

Are there any observations that you've gleaned from travelling in space about what humankind is doing to the planet?

Interestingly, when you go to space over a six-month period, it's hard for us to see any long-term impacts of climate change. But when you see the photographs that we've been taking over 20 years from the space station, you can see clear evidence of the impact that we're having. You can see evidence of climate change in terms of the volume of ice in the Antarctic, and the Arctic as well. You can see mass areas of deforestation, and you can see glacial retreat. And what we do see on the space station routinely, when we fly over very populated areas, is large amounts of smog and atmospheric pollution. On the southern part of the Himalayas, for example, it's a completely brown slate of smog. On the Tibetan side it's crystal clear; it's a very stark illustration of what impact humans are having.

The other thing I think really strikes you as an astronaut is when you see every sunrise and sunset – we get 16 of them a day, plenty of sunrises and sunsets. There are a few moments where you can see the curvature of the Earth, and you see how thin the atmosphere is. It's about 16 kilometres [9.9 miles] thick, so it's tiny. And that's what really brings it home, thinking wow, you know, that's what makes it different to Mars and Venus. It's just that thin layer of gas that protects all life on the planet.

When you see wildfires in Canada or California, you see how the smoke was spread over the entire continent of North America, or you see a sandstorm in the Sahara and see it spread out from France and Portugal to the UK, it again highlights just how thin that atmosphere is. Our pollution, whether it's natural in terms of forest fires or sandstorms, or whether it's human-made, it doesn't have much room to move, it has to spread out. We're all breathing the same air, and I think that's the biggest impact on you that you have as an astronaut.

© ESA/NASA

Above: Peake completes an extravehicular activity, venturing outside the ISS

Left: Floating with a view of his home planet in the Cupola module

© ESA

> THE FURTHER WE TRAVEL FROM EARTH, THE MORE PRECIOUS OUR HOME PLANET SEEMS TO BE

What was your first thought as you left Earth's atmosphere?

The first thought, I guess it's kind of relief that you made it safely. Not that we expected it to go wrong, but actually there are many delays and problems. The first thought as you make it into orbit is a look between the crew members to think 'yes, we're here. We made it'. And then it's a look outside the window. Absolutely phenomenal, that view of Earth from space. And certainly as a rookie astronaut looking at it for the first time is amazing. The sense of speed is unbelievable during third stage, as the rocket is getting you up to 27,500 kilometres [17,088 miles] per hour – ten times the speed of a bullet. And you don't notice that the first couple of stages in launch are all about power acceleration. It's about 9 million horsepower, doing four gs of acceleration, so eight minutes and 48 seconds is a long launch period. But the latter stage is just about acceleration getting knocked off orbital velocity. So when you take that first look outside the window, you can't believe how fast you're covering the planet's surface.

Speaking of things going wrong in space… what's the most dangerous incident that has ever happened?

When you venture on a spacewalk, you know that you're doing the highest risk element of any mission in space, but probably the last thing you'd expect to happen is to drown. This actually nearly happened to my Italian classmate Luca Parmitano back in 2013. He was on his first spacewalk, and he felt water coming into his helmet.

Mission Control thought it must be coming from his drink bag, so they said, "Luca just drink it; the bag must be leaking," which he did. The water feels very cold, and the drink bag's now empty and there is still water coming in. They realised they had to get Luca back in a hurry, and by the time Luca got back to the airlock, the water had come completely over the top of his head. It cut out all of his communication systems, so he couldn't hear. He couldn't talk. He couldn't see because the water was in his eyes and coming over the top of his nose and mouth. It was the closest we've come to losing a crew member on the space station.

When we were out in space for about four hours, Tim Kopra pulled up and said: "I've got water coming into my helmet." In fact, he was using the same spacesuit that Luca had used a few years prior, so we knew it was a dangerous situation. We had to get Kopra back into the airlock in a hurry and terminate the spacewalk. But, interestingly, NASA had introduced two changes to the spacesuit since Luca's incident. One was to have a breathing tube that went from the helmet down to the torso, so at least you could put your mouth over this breathing tube and breathe from a different part of the spacesuit. And the second was to have a nappy in the back of that particular helmet to absorb any water that could come again.

I thought you might like to know a snorkel and a nappy – it doesn't always take a high-tech solution for solving a complex problem.

Did going into space change your thoughts on Earth?

The one thing that strikes me – and I know this is the same for all of my astronaut colleagues as well – is that the further we travel away from planet Earth, the more precious our home planet seems to be. From space it is startlingly clear to see that there is no planet B. Space is an enabler for so many technologies and innovations back on Earth – whether it's conservation, monitoring the impacts of climate change and giving us the vital data that we need to have our finger on the pulse of our planet, or whether it's tracking the logistics of things such as shipping and aircraft, providing navigation or communication systems or real-time data enabling us to make decisions such as what's the weather doing. But in order to use the space environment responsibly, we also need to consider the impact on the planet as well, which is why I'm really encouraged to be working and see companies which are developing very low-carbon fuel in order to get us into space – and, of course, developing these technologies which are enabling us to be more innovative and recycle and reuse parts of rockets and spacecraft, too.

We have to protect the space environment for future generations. There are currently more than half a million pieces of space debris just in low-Earth orbit, so we really need to take responsibility for cleaning up space, to remove the defunct satellites and regulate the new ones that are going up there, or else we're going to risk losing this environment, and our ability to operate in this domain. This is where technology and innovation really comes into the equation. It provides solutions for today's problems.

As we shine the spotlight on transportation and logistics, I for one am really excited to have learned more today, and to continue to learn more about how we can all contribute to a better and more prosperous future.

The International Space Station is being used as a platform for virtual reality (VR) and augmented reality (AR). In terms of those VR and AR systems, we're also using the space station as this platform for technology and innovation, using robotic technology more and more to explore hazardous or hostile environments, but also sometimes to conduct mundane, repetitive or time-consuming tasks. I was controlling what is now the Rosalind Franklin rover, which will be launching to Mars next year. I was controlling that from the space station in orbit down to Mars Yard in Stevenage. This was testing a command and control system that's going to be absolutely essential for when we start doing those longer exploration missions. My NASA colleague Chris Cassidy was using haptic feedback for humanoid robotic systems that can help us outside on a spacewalk – and even maybe one day fully replace us from a spacewalk to do certain tasks. These kinds of things that require a high level of fidelity and precision are absolutely essential to get the robotic technology right.

How does this help space navigation?
Simulation technology helps us to de-risk our activities as well. I practised how to capture a visiting cargo vehicle, and we spoke about the logistics of delivering cargo to the International Space Station. We need cargo vehicles about four times every year minimum to resupply us all of our food, our clothing and all of the scientific experiments that we're doing. But capturing a cargo vehicle in space is a really high-pressure moment for any astronaut. I must have practised this at least 100 times before actually going into the live capture itself. But when you've got $100 billion (£72 billion) of space station at stake and a couple hundred million dollars of a cargo vehicle, then those famous NASA words of 'failure is not an option' really spring to mind.

When you also bear in mind that both of these, when you go to capture a vehicle, you have to put the space station into what's called free drift and the cargo vehicle into free drift as well, because you don't want any unwanted thruster commands changing the orientation of those vehicles. So the space station and cargo vehicles are just tumbling in space, and as astronauts we have a precious 90-second window to grab this robotic arm drive again, using free manual controllers, and get hold of our cargo vehicle. This Dragon spacecraft that was cleaning up cargo, this is the one I captured in 2016 that actually had another interesting piece of cargo on board, called the Bigelow Expandable Activity Module. It was the first flat-pack module to be flown and tested in space – maybe not quite like here in space, but not that far off. We actually use the atmosphere on board the space station to inflate it to its full size. This is being used now as a prototype for a larger space station for the future, and is still on board the space station right now.

Are there any habits you picked up in space?
In terms of structure and routine, it's really helpful on the space station that everything runs to a very clear structure and routine. And that's something I like to do in my life back here, because I think it helps, especially during lockdown. It really helps you just maintain that work-life balance. Exercise, for example, was something that was considered a luxury that happens when you get a few moments every day to go do something as opposed to being a scheduled routine activity that you need to set time aside for. On the space station, everything is scheduled, with time allocated for everything, and it really just ensures that you get the basics of work, rest, nutrition and sleep.

What do you think was the coolest experiment you carried out in space?
There are loads of really cool experiments. We're looking at metal alloys, which are really cool. We also did some combustion experiments. Normally we don't like to set fire to things in space, but we were actually looking at how a flame propagates in a weightless environment. This is looking at combustion techniques which could help our efficiency of combustion engines down on Earth, so that was a really exciting experiment.

Another one we did was using the airlock to actually reduce the pressure, looking at airway inflammation. This is something that's going to help asthma sufferers back down here on Earth. And we had to go to quite a low pressure in the airlock. That was actually the first time we'd used the airlock as an experiment.

How do you see space travel evolving?
Electric is a strong possibility. There's all sorts of different methodologies being investigated. Ion thrusters, for example, looking at that as a slow but steady form of acceleration for a mission for a spacecraft. We're looking at solar sail technology as well. All sorts of different technologies, even laser-based technologies – using lasers to actually assist with rocket thrust.

We're looking at all sorts of different technologies as to how you can minimise the amount of carbon required to get objects into space, and that's the main effort that's been going on right now. Rockets take up a huge amount of energy, but if we can do it from a single stage to launch – something like the way Reaction Engines are trying to build this SABRE engine – the entire spacecraft will be able to land with no jettisons, a complete single-station launch, which will be an absolute game changer. So yes, the space industry is working towards that.

Right: Peake exits his capsule after landing back down on Earth in June 2016

© Getty

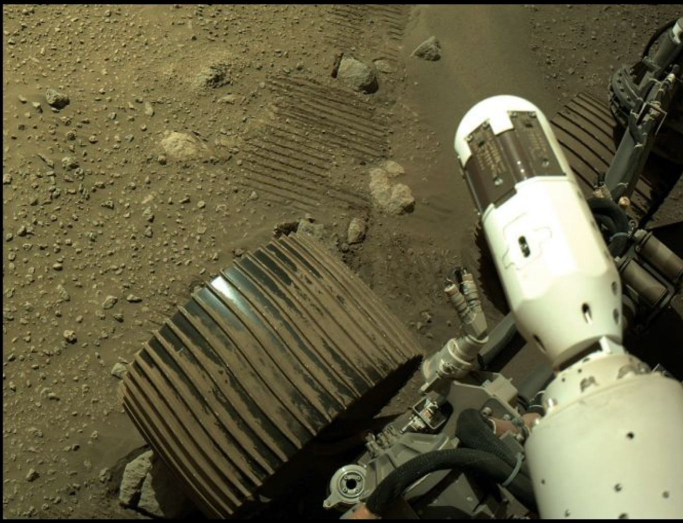
NASA'S PERSEVERANCE ROVER TAKES ITS OWN WHEEL FOR MARS DRIVES

Auto-navigation on the Red Planet: "It's a rover driver's paradise"

Reported by Meghan Bartels

NASA's Perseverance rover is picking up the pace on Mars thanks to technology that helps the robot avoid running into trouble on its otherworldly drives. That technology, called AutoNav, is a navigation system that maps terrain and plans routes without the rover needing to rely as heavily on guidance from Earth. AutoNav is four or five times more powerful than equivalent technology tested on NASA's previous Mars rover, Curiosity, which means Perseverance will be able to take more direct routes and travel faster, in turn allowing the rover to do more science in the same amount of time.

"We're going to be able to get to places the scientists want to go much more quickly," Jennifer Trosper, project manager for the rover at NASA's Jet Propulsion Laboratory (JPL) in California, said. "Now we are able to drive through these more complex terrains instead of going around them. It's not something we've been able to do before."



Right: Perseverance is faster and easier to control than past rovers

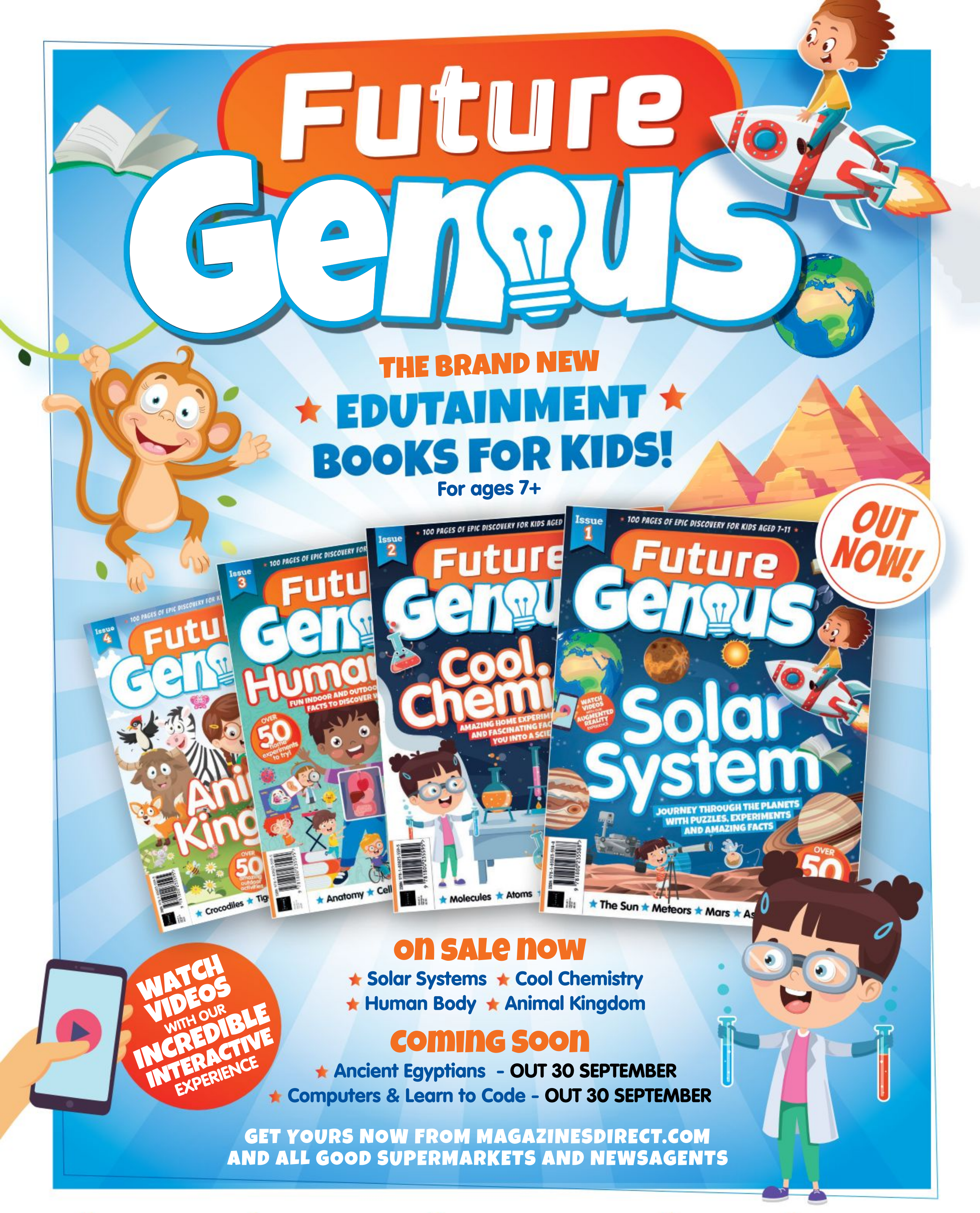
© NASA / JPL Caltech

The AutoNav process doesn't cut out human drivers entirely - it just increases the rover's autonomy where possible. "We have a capability called 'thinking while driving'," said Vandi Verma, a senior engineer, rover planner and driver at JPL. "The rover is thinking about the autonomous drive while its wheels are turning."

Other features on the new rover will also help increase speed. Perseverance's wheels have a larger diameter, narrower width and wavier tread pattern which mission engineers designed to increase traction and durability on Mars. Perseverance also carries an entirely separate computer devoted to navigation, and the new rover's belly clearance is higher, making a wider variety of terrain safe for exploring.

All told, the improvements implemented for Perseverance mean the rover could travel as fast as 120 metres (393 feet) per hour - just over the length of a football field - compared to Curiosity's speed of 20 metres (66 feet) per hour. That would put Perseverance's top speed at about 0.12 kilometres (0.07 miles) per hour. Increasing rover speed for Perseverance is important because mission scientists hope to direct the rover to cover a total of 15 kilometres (nine miles) over the course of its mission.

That's exciting not just for scientists, but also for the humans helping Perseverance navigate, who get to enjoy more of the Red Planet's scenery in Jezero crater. "Jezero is incredible," Verma said. "It's a rover driver's paradise. When you put on the 3D glasses, you see so much more undulation in the terrain. Some days I just stare at the images."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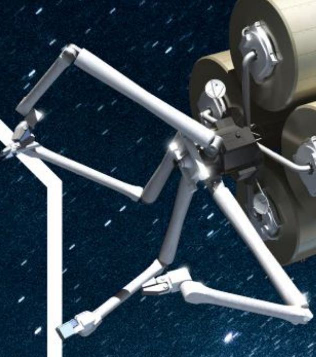
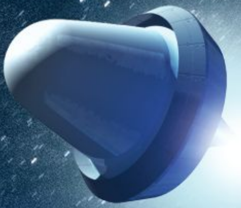


10 SPACE INNOVATIONS



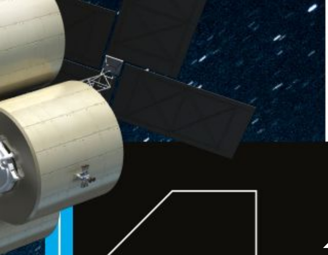
GROUNDBREAKING TECHNOLOGIES THAT WILL REVOLUTIONISE HOW WE EXPLORE THE COSMOS

Reported by Jonathan O'Callaghan

As our ambitions for exploring space become greater, so too do our technological needs. Our current technologies and methods place limits on what we can do, limits that we are starting to press upon as more daring and exciting missions are devised.

To fulfil our grander ambitions, a variety of companies and agencies are carrying out the research and development that will provide the new technologies we need – from advanced propulsion techniques to reusable rockets.

With that in mind, we've chosen ten technologies that we think could revolutionise our methods of exploring and understanding the universe around us. Some are proposals we'd expect to see in the next few years; others are wholly more ambitious concepts. Join us as we unveil the incredible future space technologies that will change our methods of space exploration and observation forever.



1

Environment transformers

On the Moon, Mars, Mercury and potentially other worlds within our galaxy, we know of permanently shadowed craters and caves that receive no sunlight. These areas are of particular interest to scientists as they may contain significant quantities of ice that could be studied. However, the problem with ice is that it's pretty solid. Unless you've got a human explorer or a rover with a drill, it's difficult to do anything with it. That's where transformers come in. These multifunctional platforms would be placed at the rim of a crater, where they would then reflect incoming sunlight, using mirrors, onto specific sections of the ice. This would melt it, allowing an automated rover to analyse the resultant water.

This incredible technology could provide us with a low-cost option for accessing ice and water across the Solar System, giving us clues into planetary formation and perhaps even supplying future astronauts with a resource of water.

> "THESE AREAS ARE OF PARTICULAR INTEREST TO SCIENTISTS AS THEY MAY CONTAIN SIGNIFICANT QUANTITIES OF ICE THAT COULD BE STUDIED"

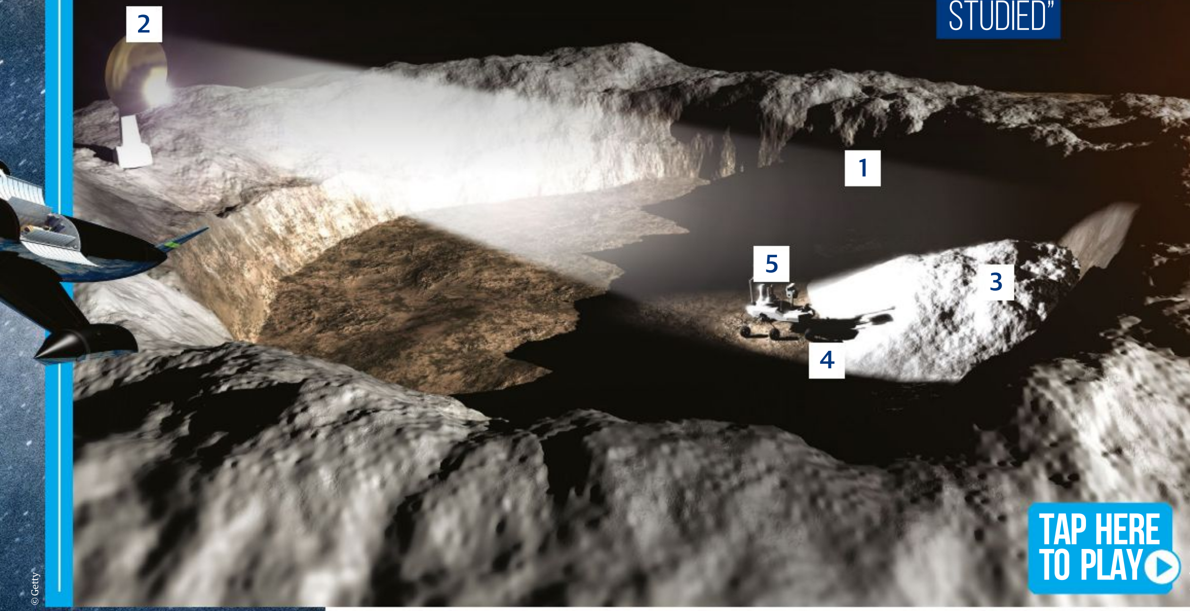
1 SUNLIGHT Some craters that we know of are permanently shadowed, receiving no sunlight and enabling ice to remain present.

2 TRANSFORMER A transformer would be placed at the rim of a crater, reflecting incoming sunlight onto some of the ice.

3 ICE Ice found on worlds such as Mercury and Mars could contain secrets into the planets' history and formation.

4 ROVER An automated rover placed on the ice would analyse the areas melted by the transformer, getting access to liquid water.

5 POWER An added bonus of this proposal is that the reflected sunlight could help power solar panels on the rover.



TAP HERE TO PLAY

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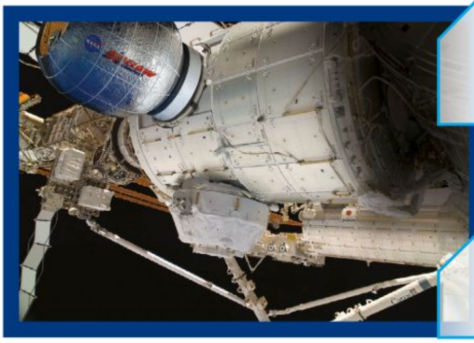


© NASA

2

Inflatable space stations

Could we send compact space stations up into orbit, having them then unfold in space by pumping gas into them? Bigelow Aerospace thinks so, and it's hard at work on such technology. Bigelow has actually already tried and tested this idea with its Genesis I and II modules in 2006 and 2007 respectively. The company then successfully connected an inflatable habitat to the ISS in 2016. The ultimate step will be to launch a standalone module, called the B330, that can inflate and operate by itself in orbit, forming the world's first inflatable station to be used for scientific endeavours, but also as a 'hotel' of sorts for tourists to visit.

3

Tiny robots on Titan

Landing on other worlds has always been a struggle. You have to contend with gravity and possibly an atmosphere as you make your way to the surface, often employing complex and sophisticated landing mechanisms that are not only costly, but also risky. Apparently, though, when a team at NASA made a tensegrity structure like the one below, they accidentally dropped it on the floor and it survived, intact. They wondered if the same sort of structure could be dropped onto the surface of another world without needing to use parachutes or rockets to lower it to the surface. The answer is probably yes.

Small and low-cost missions are going to be increasingly important as we move forward in our space exploration endeavours. This particular idea involves using tensegrity structures - ones with interlocking tubes that create a net tension across the entire structure - to land on another world such as Titan without the need for an additional landing mechanism. By being dropped from a spacecraft in orbit or flying past Titan, the structures could be left to fall through the atmosphere and land on the ground, ready to perform experiments with no mission-ending damage.

Tens or perhaps even hundreds of these small machines could be packed into a spacecraft for distribution at Titan. Each could contain different experiments, ranging from cameras to environmental sensors, while the machines would also be collapsible, allowing them to get direct analysis of the ground.

It's an ambitious proposal, but it's one that seems to be entirely possible. And it's not just Titan these could be used on - the high-impact absorption of these robots means they could also be employed pretty much anywhere in the Solar System.

1 DROP

Perhaps hundreds of these tiny robots could be dropped from a spacecraft in orbit around Titan, making their way to the surface with no landing mechanism.

2 IMPACT

The tensegrity structure allows the robots to withstand the high-impact forces they will experience when they make contact with the ground.

3 COLLAPSE

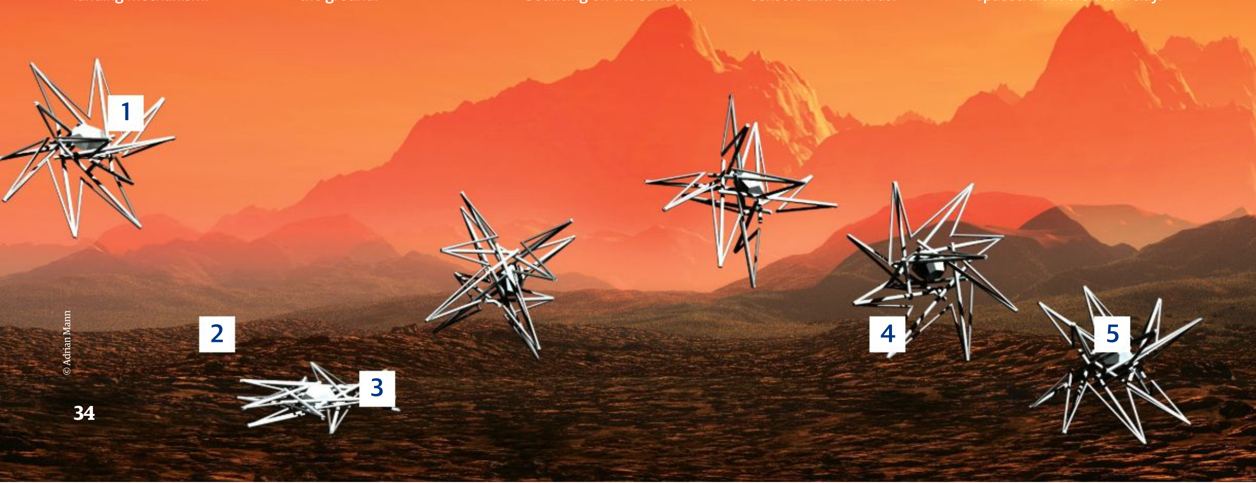
The robots can collapse to help them withstand the force of landing, transferring the energy of the impact away and resulting in the robots bouncing on the surface.

4 EXPERIMENTS

Within each tube the robots could contain a number of experiments to study the surface of Titan, including environmental sensors and cameras.

5 OPERATION

The robots would be able to perform extensive scientific analysis, such as collapsing to study the ground, while transmitting their findings to a spacecraft in orbit for relay.



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Laser thrusters

One of the biggest limits upon our exploration of the Solar System is fuel. To traverse large distances you either need a lot of fuel, or a clever path that incorporates the gravitational pull of the planets. Carrying large amounts of fuel comes at a cost, and not just a financial one – it also restricts how much useful payload you can take, such as scientific instruments.

It has long been desirable to build a spacecraft that can be pushed by a new form of propulsion that breaks the limits of what is currently possible. One such solution might be a recent NASA proposal that suggests we could build propellantless spacecraft pushed along by photons – light particles – or lasers.

The technology is very much in its infancy, but it's very intriguing nonetheless. One concept could see a solar array in Earth orbit direct photons onto a spacecraft. A 100kW solar panel would produce up to one Newton of constant photon thrust on a spacecraft, accelerating it to high speeds.

> "IT WOULD ALLOW US TO BUILD STRUCTURES IN SPACE AS OPPOSED TO LAUNCHING THEM FULLY COMPLETE FROM EARTH"

In-orbit assembly

To become a true spacefaring civilisation we will need to learn how to construct spacecraft in space rather than launching them from Earth. With that in mind, aerospace company Tethers Unlimited has proposed a new technology called SpiderFab that will be able to build structures in orbit from materials fed into the machine. SpiderFab would be launched into orbit by a rocket, and once there would use spools of material – most likely carbon fibre – to assemble huge structures.

The material is fed from spools to a 3D printer, turning it into a 'web' of sorts that the arms can then contort into the required structure. This could be a variety of things, including a support structure for a solar array or the backbone of a telescope. If successful, this technology would be revolutionary; it would allow us to build structures in space as opposed to launching them fully complete from Earth.

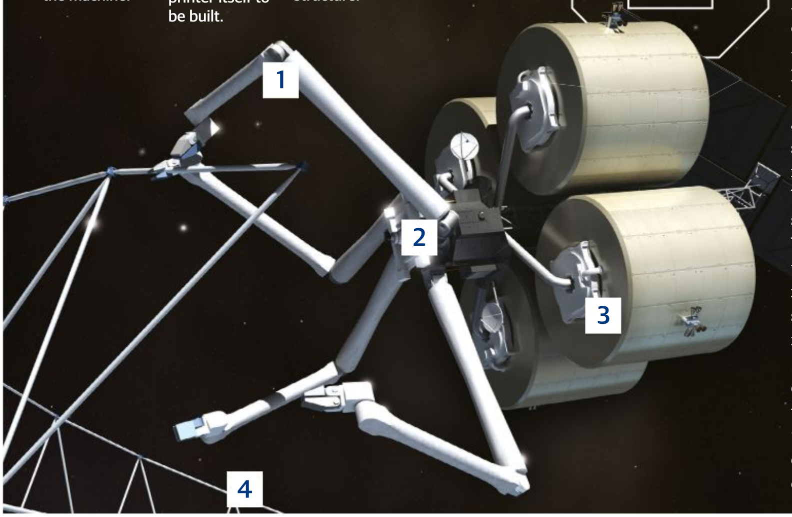
With the necessary funding, SpiderFab could be ready for a small demonstration within a few years. A prototype, the 'Trusselator', which will use spools of carbon fibre to make high-performance composite trusses is being prepared.

1 COMPACT The use of SpiderFab would enable structures to be launched compactly before being built in orbit by the machine.

2 3D PRINTING SpiderFab will use an inside-out 3D printer, allowing structures much larger than the printer itself to be built.

3 SPOOLS Material is held in spools on SpiderFab before being 'spun' by its arms into the required shape of the structure.

4 STRUCTURES The structures that could be built by SpiderFab include large antenna reflectors and solar arrays.



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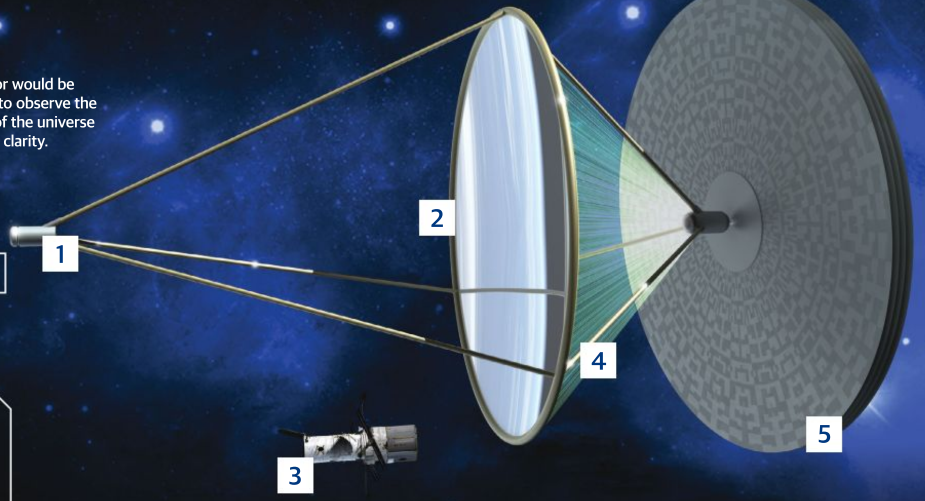


1 OPTICS The huge mirror would be sensitive enough to observe the farthest reaches of the universe in unprecedented clarity.

2 MIRROR A 'photonic muscle' telescope would use a nanoengineered mirror shaped to 1,000th the width of a human hair.

3 DENSITY This incredible structure would be less dense than a feather, with a mass 100 times less than Hubble.

4 SHAPE The huge structure would be built in space, perhaps by a spacecraft like SpiderFab which can build in-situ.

5 SUNSHADE The super telescope would have a sunshade to protect its optics from the glare of the Sun.

© Adrian Mann

6 Super telescopes

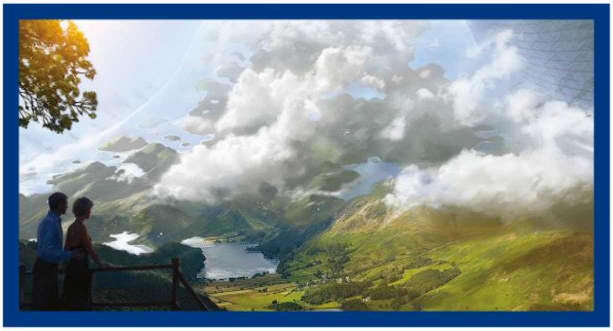
NASA is currently in the process of investigating an innovative new way of building telescopes that could completely change how we view the cosmos. Known as Ultra-Light Photonic Muscle Space Structures, these huge 'super telescopes' would be significantly larger, but also significantly cheaper than current space-based telescopes such as Hubble.

© Adrian Mann

7 Observing exoplanets

In November this year, NASA's James Webb Space Telescope (JWST) will launch, the most powerful space telescope humanity has ever built. While it will offer unrivalled views of the cosmos, some scientists have suggested that there are additional features we could use with the JWST to revolutionise the field of astronomy.

One of those is to launch a starshade with the telescope. The technology has been around for years, but budget restraints have seen it remain a concept rather than an actual mission. A giant shade would be used to block the light of a distant star known to harbour exoplanets, and a powerful telescope, such as the JWST, would peer just past the shade and be able to directly observe the exoplanets. Such a proposal for a starshade-centric telescope is currently under consideration by NASA for funding. If picked, it could offer a whole new insight into exoplanets.



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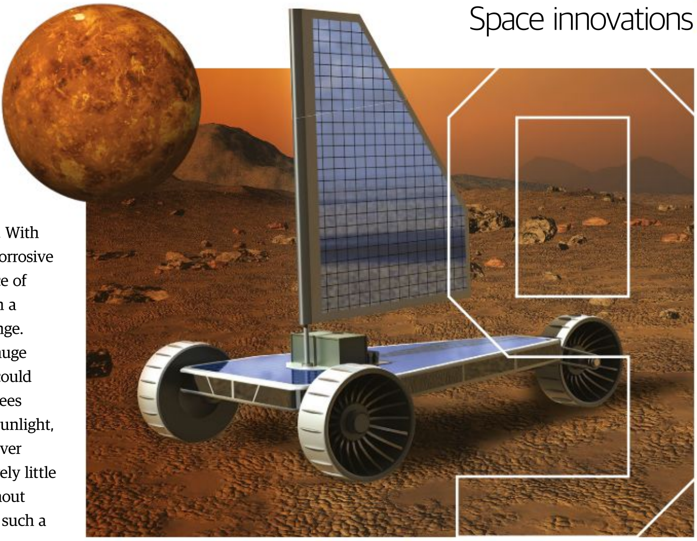
8 Space habitats

A recent concept proposal to NASA has suggested that the tensegrity structures we discussed for use on Titan could also be used to build a space habitat near the Moon, albeit on a far larger scale. The lightweight structure would use water gleaned from space-based materials as a means to provide shielding for its inhabitants. Known as Growth-Adapted Tensegrity Structures, these could be an excellent way to build large-scale habitats in space.

Windsailing on Venus

One of the most hostile places in the entire Solar System, the surface of Venus is also incredibly intriguing thanks to its fascinating climate, bizarre history and turbulent present. With a surface temperature hot enough to melt spacecraft and a corrosive atmosphere, so much so that our only missions to the surface of Venus, the Soviet Venera probes, could survive no more than a couple of hours on the surface, landing there is a real challenge.

Landing a rover on the surface of Venus would require a huge engineering marvel. The rover would need electronics that could survive temperatures of up to 450 degrees Celsius (842 degrees Fahrenheit) in addition to solar cells that could get enough sunlight, even with the thick Venusian atmosphere. A sail-powered rover would enable a vehicle to operate on the surface with relatively little amounts of energy; it could drift on the winds of Venus without needing to drive itself much. According to a NASA proposal, such a mission is not too far off being possible.



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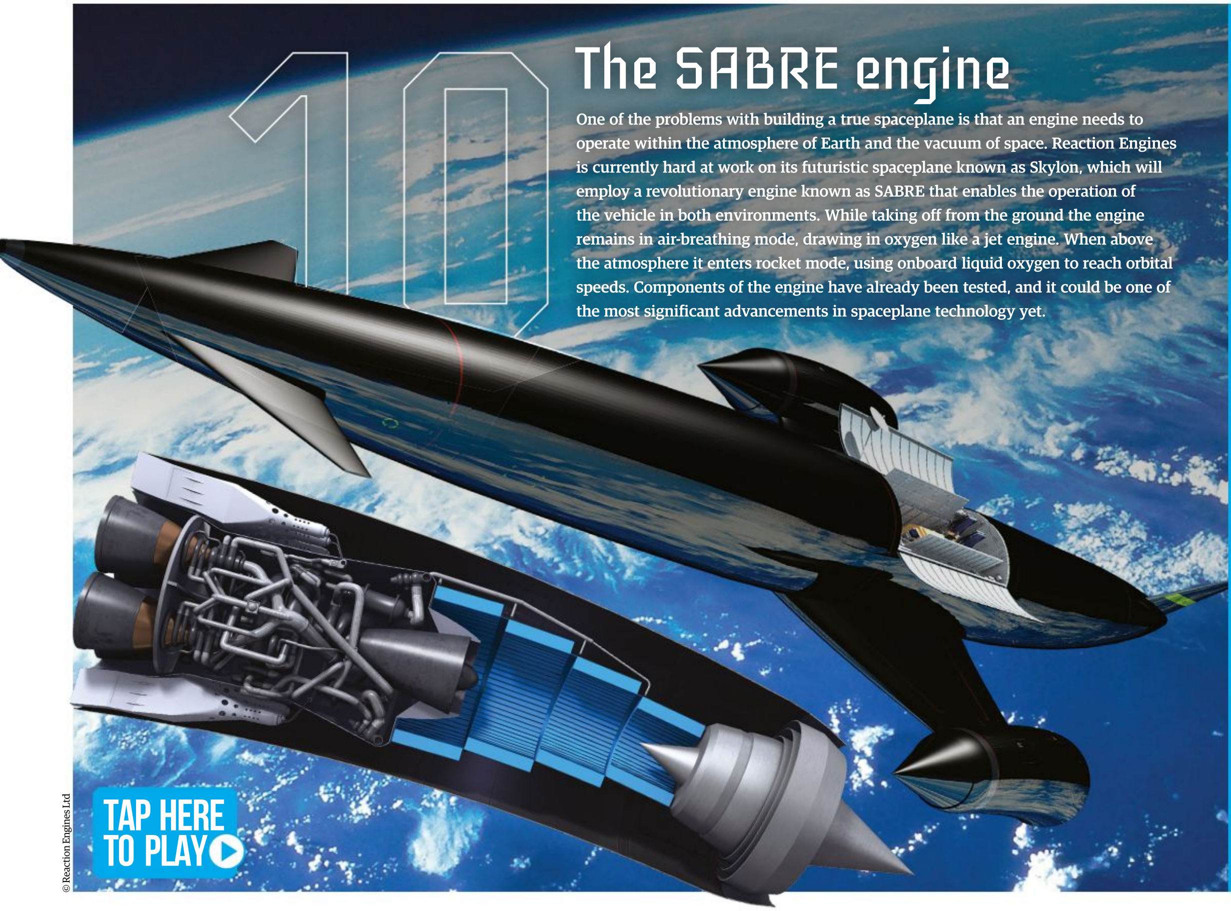

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The SABRE engine

One of the problems with building a true spaceplane is that an engine needs to operate within the atmosphere of Earth and the vacuum of space. Reaction Engines is currently hard at work on its futuristic spaceplane known as Skylon, which will employ a revolutionary engine known as SABRE that enables the operation of the vehicle in both environments. While taking off from the ground the engine remains in air-breathing mode, drawing in oxygen like a jet engine. When above the atmosphere it enters rocket mode, using onboard liquid oxygen to reach orbital speeds. Components of the engine have already been tested, and it could be one of the most significant advancements in spaceplane technology yet.

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Northern Lights will give you a complete understanding of one of the true wonders of the natural world and leave you prepared for the adventure of a lifetime.

COLLINS STARGAZING: BEGINNERS GUIDE TO ASTRONOMY £9.99

A brilliant introductory guide to exploring the night sky from the astronomers of the Royal Observatory Greenwich. Offering complete advice from the ground up, *Stargazing* is the perfect manual for beginners to astronomy, introducing the world of telescopes, planets, stars, dark skies and celestial maps. Discover how to tackle light pollution, how to stargaze with just your eyes and what equipment is best for beginners.

Astronomy experts Radmila Topalovic and Tom Kerss explain the best ways to plan your stargazing experience and the key things to look out for on specific dates throughout the year. With seasonal star charts, constellation charts and facts about our Solar System, *Stargazing* is packed with useful information and guidance for both the Northern and Southern Hemisphere. Bridging the gap between human curiosity and the need for scientific expertise, *Stargazing* allows a complete novice to understand our place in the cosmos.

2022 GUIDE TO THE NIGHT SKY: A MONTH-BY-MONTH GUIDE TO EXPLORING THE SKIES ABOVE BRITAIN AND IRELAND £6.99

From the top astronomy publisher comes the bestselling stargazing handbook to the planets, stars and constellations visible from the Northern Hemisphere. There are six pages for each month, covering January to December 2022. This practical guidebook is an easy introduction to astronomy and a useful reference for seasoned stargazers.

Designed for Britain and Ireland but usable anywhere in the world between 40 and 60 degrees north, it covers most of Europe, southern Canada and the northern United States. Inside you'll find advice on where to start looking and a map of dark-sky sites to avoid light pollution, charts for the circumpolar and seasonal constellations, easy-to-use star charts for each month with descriptions of objects and events to look for in 2022, positions of the Moon, visible planets and eclipses.

> “NEVER MISS A NIGHT SKY EVENT, WHEREVER YOU ARE IN THE WORLD”

Collins
ROYAL OBSERVATORY GREENWICH
MOONGAZING
BEGINNER'S GUIDE TO EXPLORING THE MOON
Tom Kerss
Night Sky ALMANAC
A STARGAZER'S GUIDE TO 2022
Storm Dunlop & Wil Tirion
Collins
ROYAL OBSERVATORY GREENWICH
PLANISPHERE
FOR USE IN THE UK AND IRELAND, NORTHERN EUROPE AND CANADA
LATITUDE 50° N
IDENTIFY THE CONSTELLATIONS AND STARS EVERY DAY OF THE YEAR

MOONGAZING: BEGINNER'S GUIDE TO EXPLORING THE MOON £8.99

An in-depth guide for aspiring astronomers and lunar observers, it includes detailed Moon maps and covers the history of lunar observation and exploration, the properties of the Moon, its origin and orbit. This is the ideal book for Moon observers, covering essential equipment and the key events to look out for; detailed advice is given on how to choose a telescope and how to capture the Moon in sketches.

Discover all you need to know about eclipses, blue moons, supermoons, conjunctions and occultations, while a comprehensive section covers astrophotography using lenses, telescopes and smartphones, including video and how to process your images. Also included is a photographic atlas of lunar features with plates and annotated maps. A glossary of key terms, index of lunar features and software references are also provided. There's also an eBook version available for £6.49, optimised for colour tablets.

NIGHT SKY ALMANAC 2022: A STARGAZER'S GUIDE £9.99

Follow the progress of constellations throughout the seasons with this beautiful companion to the night sky. With the aid of easy-to-understand monthly calendars and maps, you will chart the rhythm of the lunar phases, discover events that light up the sky for brief periods and explore the rich tapestry of characters that adorn the starry canvas overhead.

Never miss a night sky event, wherever you are in the world, with this month-by-month guide: go meteor spotting, track the phases of the Moon and explore the constellations with worldwide coverage – with details inside for both the Northern and Southern Hemisphere – and discover fascinating celestial facts and notable astronomical anniversaries.

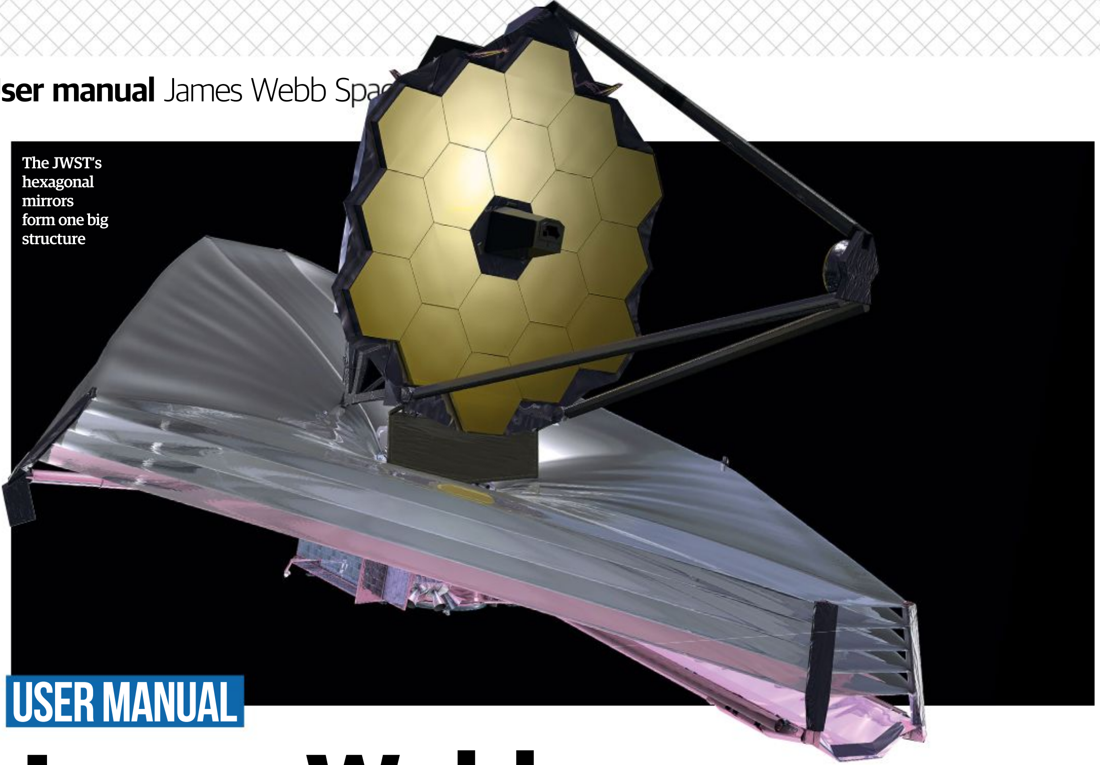
The *Night Sky Almanac 2022* is written and illustrated by astronomical experts Storm Dunlop and Wil Tirion and approved by the astronomers of the Royal Observatory Greenwich.

PLANISPHERE: LATITUDE 50°N £12.99

A star finder that allows visible stars to be identified for any date and time for certain locations in the Northern Hemisphere, it's compiled by astronomical experts Storm Dunlop and Wil Tirion and approved by the astronomers of the Royal Observatory Greenwich.

It's an easy-to-use practical tool to help astronomers identify the constellations and stars every day of the year. Just dial in the date and time by rotating the inner plastic disc showing the time until it lines up with the relevant day of the year on the outer ring. The part of the sky appearing on the planisphere will then show the arrangement of the stars above you.

This star chart is suitable for use anywhere in Britain and Ireland, Northern Europe, Canada and the northern United States. It's best viewed as near to latitude 50 degrees north as possible. The moveable disc also comes in a wallet which contains further information about stargazing.



The JWST's hexagonal mirrors form one big structure

© NASA

USER MANUAL

James Webb Space Telescope

THE SPECS

Launch: November/December 2021

Launch rocket: Ariane 5 ECA

Target: Sun-Earth L2 point

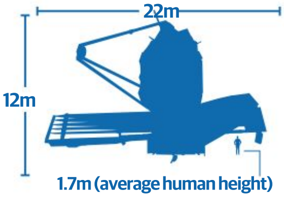
Operators: CSA, ESA, NASA and STScI

Orbital inclination: Halo orbit

Component: Multiple international components

Planned mission ends: 2031

Focal length: 131.4 metres (431 feet)



Ever since NASA launched the Orbiting Astronomical Observatory 2 spacecraft in December 1968, the scientific world has gazed out into the depths of the universe through many a generation of space telescope. For decades, two observatories have provided the most prolific and in-depth imagery of space: the Hubble and Spitzer space telescopes.

Since its launch in 1990, the Hubble Space Telescope has become an integral part of NASA's - and, by extension, the wider scientific community's - understanding of the cosmos, and in conjunction with the infrared capabilities of Spitzer, launched in 2003, our views of the star-laden skies around us have changed forever.

But like any great pioneer or innovator, the older telescopes must eventually step aside to make way for a new wave of scientific developments. And it's in the James Webb Space Telescope - named after James E. Webb, the second administrator of NASA, who helped redefine the vision of the early Space Race - that the American space agency is placing its hopes and dreams. With its 6.5-metre (21.3-foot) diameter segmented mirror, the new primary telescope will provide a whole new level of clarity to space-captured imagery.

The James Webb Space Telescope, sometimes referred to as JWST or simply Webb, began life in the wake of Hubble's journey to scientific immortality. Four years after its launch, Hubble was proving a resounding success, so NASA began to ponder the next step for space observation. What shape would they take in the coming decades as Hubble orbited towards retirement?

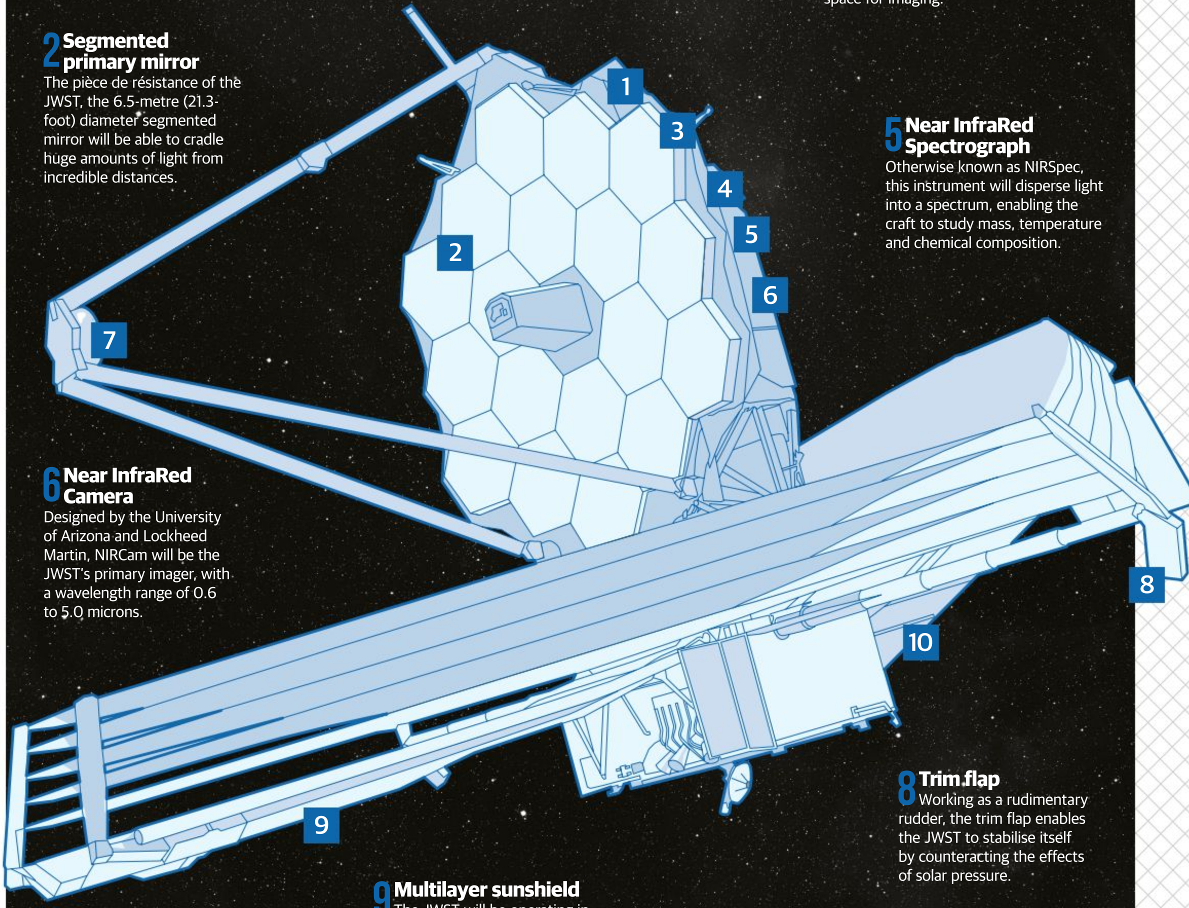
In 1996, a NASA committee convened to discuss that very subject, and it soon became apparent that certain capabilities that Hubble didn't have - such as improved infrared vision - would be vital if the next generation of telescopes were to outshine the already considerably bright Hubble.

Not only that, it would have a mirror large enough to provide greater light sensitivity and the power to see further than any other telescope before it. The teams behind this early form of the JWST wanted to do the seemingly impossible - they wanted to glimpse the very first light in the universe. NASA certainly had the dream. It then needed a plan to make it a reality.

Later that year, three teams of engineers and scientists came together to etch out a plan. A mirror 4.5 metres (14.8 feet) in diameter was conceived as an ideal, if ambitious, size for the segmented mirror, and the newly dubbed Next

Anatomy of the James Webb Space Telescope

From microshutters and lightweight mirrors to cryocoolers and infrared sensors, the JWST is jam-packed with innovation and progressive tech



1 Integrated Science Instrument Module

Otherwise known as the ISIM, this section of the craft contains the four main scientific instruments used aboard the JWST.

2 Segmented primary mirror

The pièce de résistance of the JWST, the 6.5-metre (21.3-foot) diameter segmented mirror will be able to cradle huge amounts of light from incredible distances.

3 Mid-InfraRed Instrument

This instrument, usually referred to as MIRI, combines a camera and a spectrograph in order to detect light from distant objects that our eyes are unable to see.

4 Fine Guidance Sensor and Near Infrared Imager and Slitless Spectrograph

Provided by the Canadian Space Agency, these instruments enable the JWST to pinpoint the correct points in distant space for imaging.

5 Near InfraRed Spectrograph

Otherwise known as NIRSpec, this instrument will disperse light into a spectrum, enabling the craft to study mass, temperature and chemical composition.

6 Near InfraRed Camera

Designed by the University of Arizona and Lockheed Martin, NIRCam will be the JWST's primary imager, with a wavelength range of 0.6 to 5.0 microns.

7 Secondary mirror

In conjunction with the large primary mirror, the smaller mirror reflects light from the primary mirror straight to the craft's scientific instruments.

8 Trim flap

Working as a rudimentary rudder, the trim flap enables the JWST to stabilise itself by counteracting the effects of solar pressure.

9 Multilayer sunshield

The JWST will be operating in considerably cold temperatures, but its position will see it regularly bombarded with heat from the Sun. Five thick layers will protect the craft's mirrors and prevent instruments from overheating.

10 Solar power array

The side of the craft facing the Sun will feature the solar array, which will convert sunlight to electricity in order to power the telescope.

© Adrian Mann

Unfurling the JWST

1 Ariane 5 ECA
The expendable launch vehicle will carry the JWST to its space destination. It will launch from the European Spaceport located near Kourou, French Guiana.

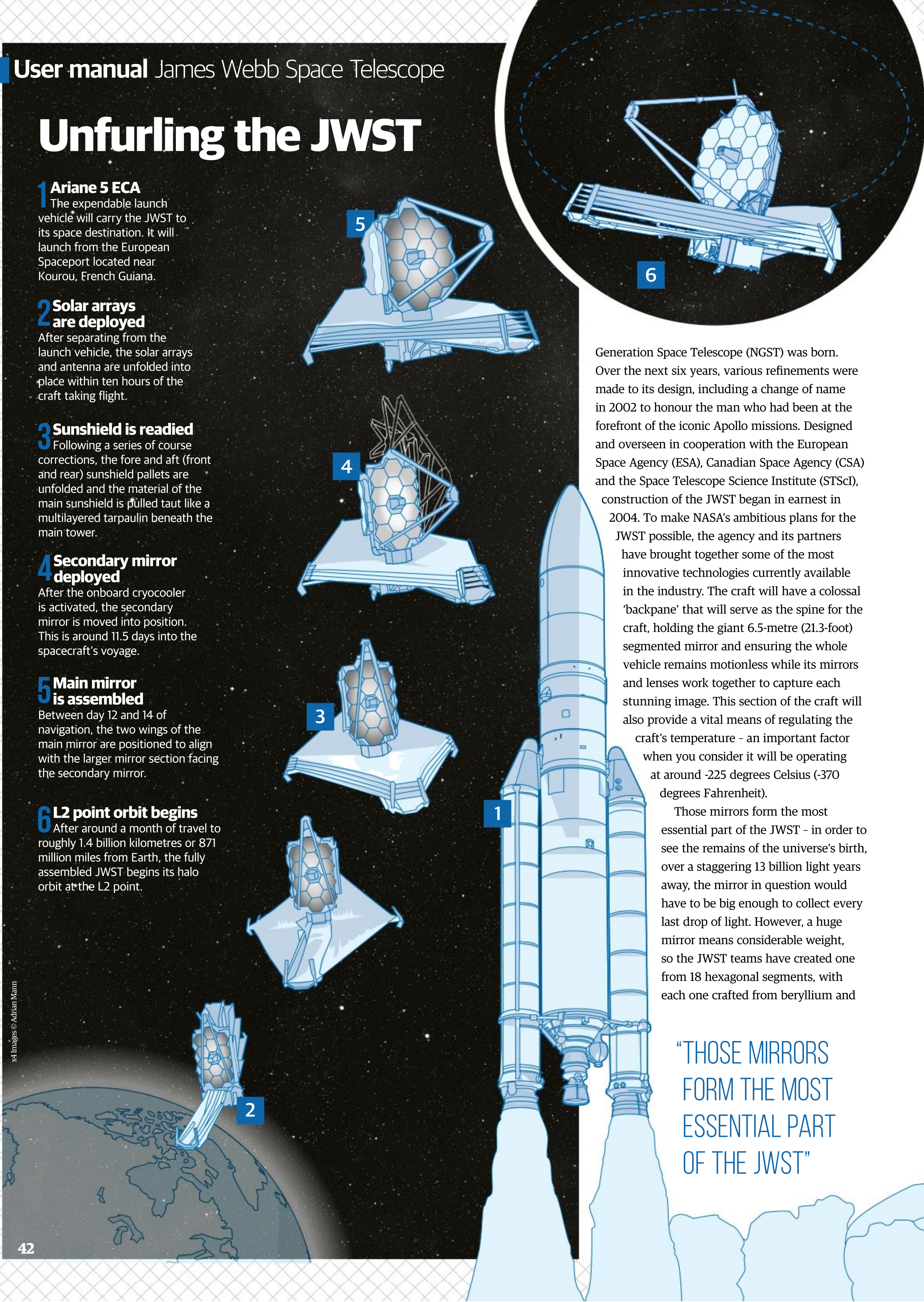
2 Solar arrays are deployed
After separating from the launch vehicle, the solar arrays and antenna are unfolded into place within ten hours of the craft taking flight.

3 Sunshield is readied
Following a series of course corrections, the fore and aft (front and rear) sunshield pallets are unfolded and the material of the main sunshield is pulled taut like a multilayered tarpaulin beneath the main tower.

4 Secondary mirror deployed
After the onboard cryocooler is activated, the secondary mirror is moved into position. This is around 11.5 days into the spacecraft's voyage.

5 Main mirror is assembled
Between day 12 and 14 of navigation, the two wings of the main mirror are positioned to align with the larger mirror section facing the secondary mirror.

6 L2 point orbit begins
After around a month of travel to roughly 1.4 billion kilometres or 871 million miles from Earth, the fully assembled JWST begins its halo orbit at the L2 point.



x4 Images © Adrian Mann

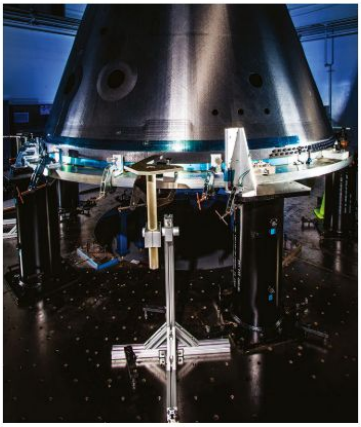
Generation Space Telescope (NGST) was born. Over the next six years, various refinements were made to its design, including a change of name in 2002 to honour the man who had been at the forefront of the iconic Apollo missions. Designed and overseen in cooperation with the European Space Agency (ESA), Canadian Space Agency (CSA) and the Space Telescope Science Institute (STScI), construction of the JWST began in earnest in 2004. To make NASA's ambitious plans for the JWST possible, the agency and its partners have brought together some of the most innovative technologies currently available in the industry. The craft will have a colossal 'backpane' that will serve as the spine for the craft, holding the giant 6.5-metre (21.3-foot) segmented mirror and ensuring the whole vehicle remains motionless while its mirrors and lenses work together to capture each stunning image. This section of the craft will also provide a vital means of regulating the craft's temperature – an important factor when you consider it will be operating at around -225 degrees Celsius (-370 degrees Fahrenheit).

Those mirrors form the most essential part of the JWST – in order to see the remains of the universe's birth, over a staggering 13 billion light years away, the mirror in question would have to be big enough to collect every last drop of light. However, a huge mirror means considerable weight, so the JWST teams have created one from 18 hexagonal segments, with each one crafted from beryllium and

> "THOSE MIRRORS FORM THE MOST ESSENTIAL PART OF THE JWST"

coated in gold to improve its reflection of infrared light. Each individual segment weighs as little as 20 kilograms, and they all fit together to create one giant instrument.

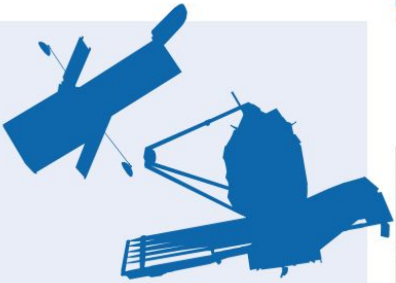
So what does the future hold for the JWST? It's already shaping up to be a big year for the craft in the run-up to its planned November launch. Currently, almost every element of the telescope has been assembled, including the huge gold and beryllium mirrors and the large 'backplane' that forms the spine of the craft. The first of its mirrors was installed at the end of November 2015. With a team of over 1,000 people from over 17 countries involved in its creation, the JWST has been a long time coming, but its mission to capture the first light of the universe has galvanised those involved, setting the stage for one of the most anticipated developments in modern space engineering.


© Northrop Grumman

Head to head

Hubble vs JWST

Aging Hubble and the upcoming JWST couldn't be any more different. Hubble studies space in optical and ultraviolet wavelengths, while the JWST will focus on infrared, which enables it to pierce thick clouds of space dust. Hubble is 13.2 metres (43.3 foot) in length - the size of a bus - but the JWST is huge in comparison. The sunshield alone is 22 by 12 metres (72 by 39 feet) - roughly the size of a tennis court.



Hubble
11,110kg

JWST
6,500kg

TOP TECH

The JWST sunshield

In order for the JWST's instruments to operate, they need to be cooled to below -223 degrees Celsius (-370 degrees Fahrenheit). To detect emissions from astronomical objects, the JWST employs a sunshield that blocks out the Sun's damaging heat and radiation while it conducts a halo orbit. The sunshield consists of five layers of Kapton, a kind of polyimide film, coated in aluminium and doped silicon, which reflects the heat of the Sun away from the craft.

© NASA

Vital statistics

6,500KG = The total mass of the rocket and payload at launch

TEN YEARS = The initial mission time for the JWST

46-52 METRES = The length of the Ariane 5 ECA rocket that will carry the JWST

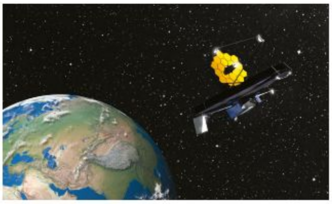
705KG = The mass of the JWST's segmented primary mirror

HOW TO...

Take photos from the L2 Lagrange point

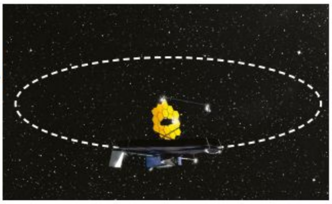
1 Building up energy

After around 30 days of travel, the JWST will need to build up enough energy to break into the gravitational pocket created between Earth and the Sun. To do this it will perform a small loop – this will create a slingshot that will launch the rocket into orbit at the L2 point.



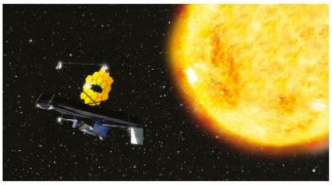
2 Staying in place

Now that it's breached the gravitational pocket of the L2 point, the JWST has to keep itself in place so that it can commence searching for the first light of the universe.



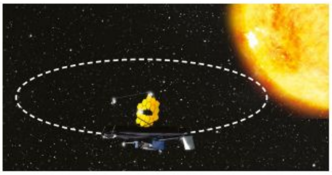
3 Maintaining direction

The back of the craft must always be facing the Sun to protect the sensitive instruments and mirrors at the front. This positioning is also vital for keeping the JWST functioning. All that sunlight isn't going to waste, as the solar panel at the rear converts it into electrical power.



4 Never losing track

The JWST won't enter the shadow of Earth and lose sight of its targets. Instead the telescope will perform its halo orbit every six months. It can capture images and data without being hindered by the position of Earth and the Moon.


x4 Images © Adrian Mann

LIGHT 'ECHOES' FROM BEHIND A BLACK HOLE

For the first time ever, scientists have seen a glow from behind one of these high-gravity objects

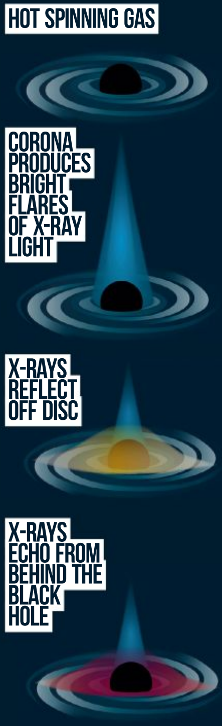
Reported by Daisy Dobrijevic

Black holes are regions in space-time where gravity's pull is so powerful that not even light can escape its grasp. However, while light cannot escape a black hole, the extreme gravity warps the space around it, which allows light to 'echo', bending around the back of the object. Thanks to this strange phenomenon, for the first time astronomers have observed the light from behind a black hole.

In a new study, researchers led by Dan Wilkins, an astrophysicist at Stanford University in California, used the European Space Agency's XMM-Newton and NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) to observe the light from behind a black hole that's 10 million times more massive than our Sun and lies 800 million light years away in the spiral galaxy I Zwicky 1.

This study began with the researchers' desire to expand our understanding of black hole coronas, which are the source of the X-ray light that often radiates from the vicinity of these objects. Bright flares of X-ray light are emitted by gas that falls into black holes from their accretion discs – the discs of dust and gas that surround and 'feed' these objects.

The team spotted an X-ray flare in I Zwicky 1 that was so bright that some of the light reflected on the gas falling into the black hole. When that reflected light was bent around the back of the black hole by the object's extreme gravity, the team was able to spot it using European Space Agency and NASA space telescopes.


HOT SPINNING GAS
CORONA PRODUCES BRIGHT FLARES OF X-RAY LIGHT
X-RAYS REFLECT OFF DISC
X-RAYS ECHO FROM BEHIND THE BLACK HOLE

© ESA

> "THE X-RAY LIGHT CHANGED COLOUR AS IT BENT AND MOVED AROUND THE BACK OF THE BLACK HOLE"

The team didn't just observe this light, which is the first time it has been directly observed like this. They also took note of how the X-ray light changed colour as it bent and moved around the back of the black hole. By observing the light's journey around the back of the black hole, the researchers hope to understand more about what really goes on that close to these gravitational vortexes.

Following this groundbreaking discovery, the team now aims to use the findings to create a three-dimensional map of the black hole's surroundings. They also hope to better understand black hole coronas and explore how the corona of a black hole is capable of producing these bright X-ray flares.

© Getty

Above: Researchers hope to map the black hole using the reflected light

WHAT IF EARTH REALLY

Earth is spherical, but what would happen if our planet were flat? We explore some of the bizarre implications of such a world, which would make life as we know it virtually impossible

Reported by Daisy Dobrijevic

© Getty

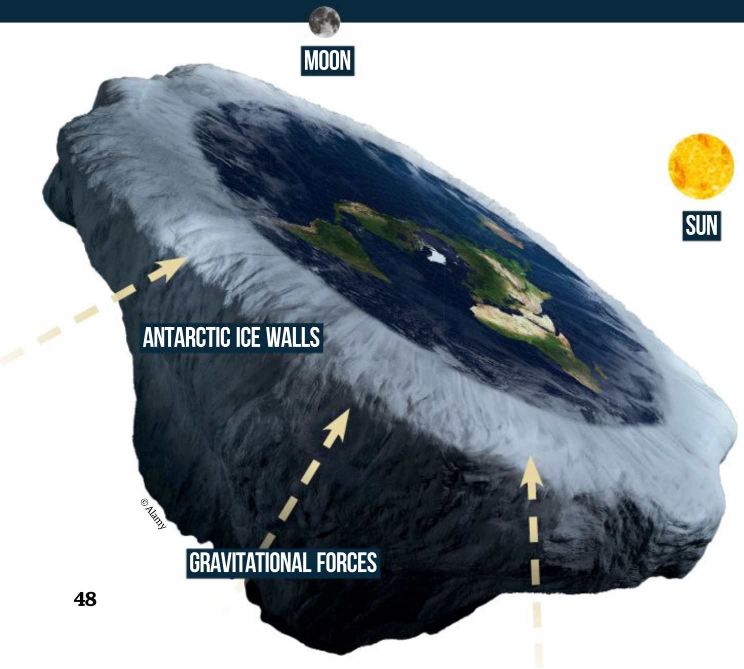
WAS FLAT?

Earth – the Blue Marble – is our very much spherical home. But let's imagine that Earth is flat. After all, there are many out there who truly believe that this is the case. How would everyday life function? Would it function at all? Here we explore how much of an oddball – or 'oddslice' – Earth would be if it were flat and whether there are any advantages to living on a strange disc with the Sun and Moon rotating overhead like characters on a cosmic carousel.

NO MORE AURORAE, AND WE'D ALL BE ROASTED

On spherical Earth, the swirling molten metal surrounding our iron core generates electric currents, which in turn create our protective magnetic field, curving around the planet from one pole to the other. But on a flat Earth, without a solid core generating a magnetic field, we would lose our protective layer - the magnetosphere. Charged particles from the Sun would no longer interact with our magnetosphere to create incredible auroral light shows. Though the absence of aurorae would be the least of our worries, as Earth would no longer be protected from the solar wind. We'd be bombarded with harmful solar radiation that could strip Earth of its protective atmosphere, leaving a barren world akin to our neighbour, Mars.

TAP HERE TO PLAY



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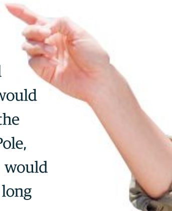
SAY GOODBYE TO GRAVITY… AT LEAST AS WE KNOW IT

On spherical Earth gravity pulls equally from all sides no matter where in the world you are. For Earth to take the shape of a disc in the first place, gravity - as we know it - must be having no effect. If it did, it would soon pull the planet back into a spheroid. Maybe a flat Earth would have no gravity at all. Or perhaps a flat Earth would cause gravity to pull to the centre of the disc: the North Pole. The further away from the North Pole, the more horizontal the gravitational tug. This would wreak havoc worldwide, but at least the world long jump record would be easily beaten - as long as you orientated yourself northwards before taking off.



© Getty

80 TO 640KM

(50 TO 400 MILES)

How high Earth's aurorae extend above the surface

> "ON A FLAT EARTH, WITHOUT A SOLID CORE GENERATING A MAGNETIC FIELD, WE WOULD LOSE OUR PROTECTIVE LAYER"

© NASA

IT WOULD CERTAINLY CLEAR THE ATMOSPHERE

With no gravity, flat Earth would no longer be able to hold onto an atmosphere. Without our protective blanket our skies would turn black, and surface life would cease to exist.

Water would boil away in the vacuum of space, and the surface temperature would plummet. But it isn't all bad news. Deep ocean-dwelling organisms that don't require oxygen - anaerobic bacteria - and those that don't need sunlight to generate food and energy - chemosynthetic bacteria - might just survive. After all, such bacteria have endured long trips in space and lived to tell the tale.

WE WOULD ALL GET LOST

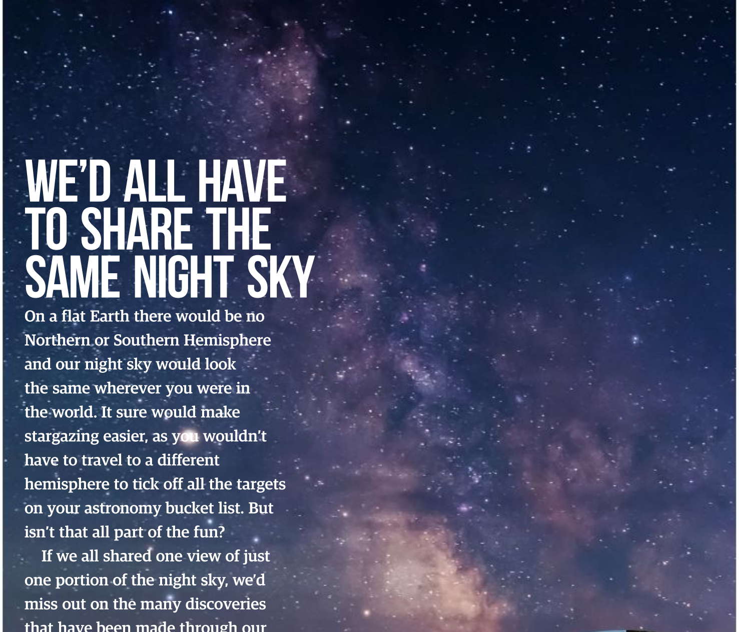
© Getty

It's very likely that satellites wouldn't exist if Earth were flat, as they would have trouble orbiting a flat plane. "There are a number of satellite missions that society depends on that just wouldn't work," says James Davis, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory. "I cannot think of how GPS would work on a flat Earth," he concludes. It's hard to imagine a world without GPS - suffice to say we'd be lost without it. On the upside, at least on flat Earth we'd have the horizontal rain to point us in the right direction… well, north.

CLOUDY WITH A CHANCE OF SIDEWAYS RAIN

If gravity pulled towards the centre of the planetary disc, rain, snow and other forms of precipitation would gravitate towards the North Pole. Only at the centre of the disc would this weather behave as we know it on our spherical Earth – falling straight down. The further from the pole you travel, the crazier and more horizontal the precipitation would be. Water would also flow towards the North Pole, and vast, bulging oceans would collect at the centre of the planet, leaving practically no water at the edges.

© Getty

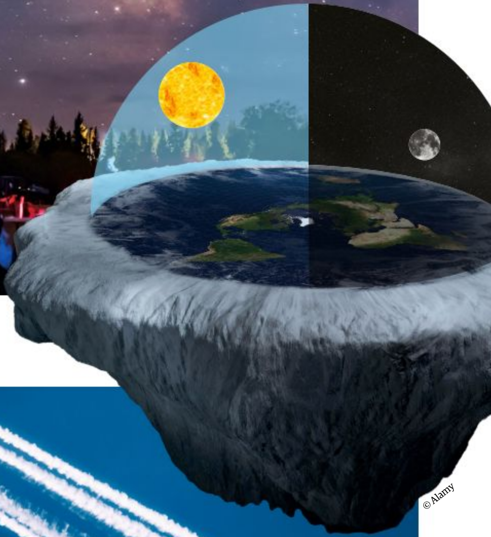


WE'D ALL HAVE TO SHARE THE SAME NIGHT SKY

On a flat Earth there would be no Northern or Southern Hemisphere and our night sky would look the same wherever you were in the world. It sure would make stargazing easier, as you wouldn't have to travel to a different hemisphere to tick off all the targets on your astronomy bucket list. But isn't that all part of the fun?

If we all shared one view of just one portion of the night sky, we'd miss out on the many discoveries that have been made through our enjoyment of a 360-degree view of the observable universe.

© Getty



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SOME JOURNEYS WOULD TAKE FOREVER

Longer travel times would be expected, not just from getting lost due to a lack of GPS, but also the distances we would need to travel. According to flat Earth belief, the Arctic lies in the centre of the planet, and Antarctica forms a giant 'ice wall' around the edge, which conveniently stops people falling off. But if you're unable to fly around the globe, and instead are forced to fly 'across' it, then travel times significantly increase. For example, to fly from Australia, which is on one side of the flat Earth map, to a part of Antarctica that lies on the other side, you would need to fly across the whole Arctic, as well as North and South America. You can also forget about trips across Antarctica -which has been achieved - as it'd be impossible due to that pesky ice wall.

© Getty

HURRICANES WOULD BE A THING OF THE PAST

Every year hurricanes, formed over the North Atlantic and Northeast Pacific, typhoons, formed over the Northwest Pacific, and cyclones, formed over the South Pacific and Indian Oceans, cause unprecedented damage. In 2017 Hurricane Harvey alone caused $125 billion (£90 billion) worth of damage in the US.

The devastating rotating nature of these tropical storms stems from Earth's Coriolis force, which causes those in the Northern Hemisphere to rotate clockwise and those in the Southern Hemisphere to rotate counterclockwise. However, on stationary, flat Earth, no Coriolis force would be generated. No Coriolis means no hurricanes, typhoons or cyclones. This is also why we don't see these storms between five degrees north and south of the equator, as the Coriolis magnitude is zero at the equator.

TAP HERE TO PLAY

480KM

(300 MILES)

The average diameter of a hurricane

> "THE DEVASTATING ROTATING NATURE OF THESE TROPICAL STORMS STEMS FROM EARTH'S CORIOLIS FORCE"

© Alamy

© NASA

© Getty

THE THEORIES OF STEPHEN HAWKING

Some of the late physicist's theories revolutionised the way we view the universe, but others still leave scientists scratching their heads

Reported by Andrew May

Stephen Hawking was one of the greatest theoretical physicists of the modern age. Otherwise known for his appearances in popular media and his lifelong battle against a debilitating illness, his true impact on posterity comes from his brilliant five-decade career in science. Beginning with his doctoral thesis in 1966, his groundbreaking work continued nonstop right up until his final paper in 2018, completed just days before his death at the age of 76.

Hawking worked at the intellectual cutting edge of physics, and his theories often seemed bizarrely far out at the time he formulated them. Yet they're slowly being accepted into the scientific mainstream, with new supporting evidence coming in all the time. From his mind-blowing views of black holes to his explanation for the universe's humble beginnings, here are some of his theories that were vindicated, and others that are still up in the air.

TIMELINE

OCTOBER 1959

Began studying at University College, Oxford, aged 17.

OCTOBER 1962

Became a doctoral student at Cambridge under Dennis Sciama.

FEBRUARY 1963

Diagnosed with amyotrophic lateral sclerosis following a fall while ice skating.

HAWKING'S CV

1965-1969

Research fellow, Gonville and Caius College, Cambridge

Extended the concepts of the singularity theorem explored in his PhD thesis and explored the idea that the universe may have begun as a singularity.

1969-1975

Fellowship for distinction in science, Gonville and Caius College, Cambridge

A post created specially for him. Here he proposed the laws of black hole mechanics and discovered Hawking radiation.

1975-1979

Reader in gravitational physics and professor of gravitational physics, Gonville and Caius College, Cambridge

Published his first book. Won Eddington, Maxwell, Hughes, Albert Einstein and Pius XI medals, plus the Dannie Heineman Prize. Received an honorary doctorate from the University of Oxford.

1979-2009

Lucasian professor of mathematics at the University of Cambridge

Pushed the boundaries of knowledge of black holes and the beginning of the universe. Published many books, including a 10-million-copy bestseller.

2009-2018

Director of research, Cambridge University Department of Applied Mathematics and Theoretical Physics

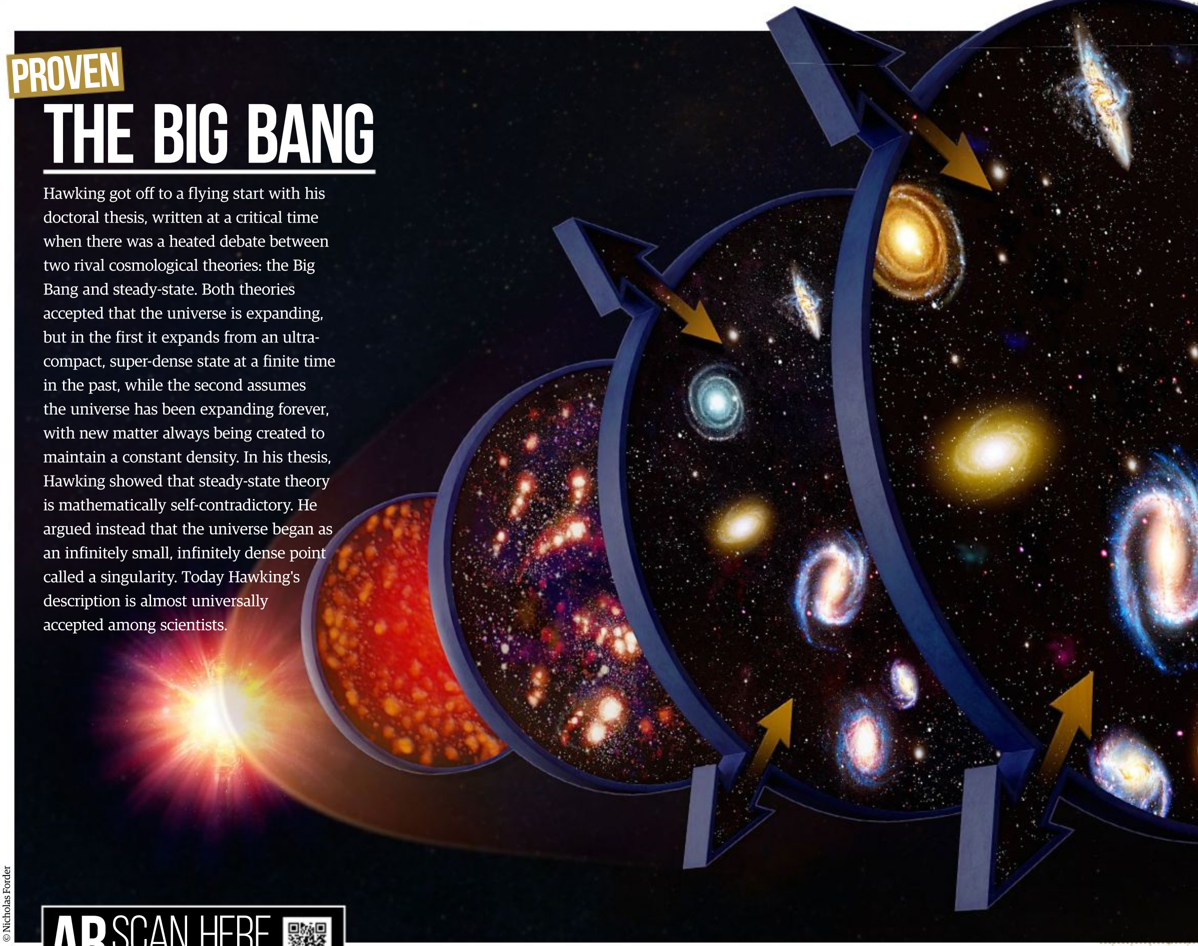
Published more books, inspired a Hollywood movie, held a party for time travellers; received the Presidential Medal of Freedom, Russian Special Fundamental Physics Prize and an honorary doctorate from Imperial College London.

> "HIS THEORIES SEEMED BIZARRELY FAR OUT AT THE TIME HE FORMULATED THEM"

PROVEN

THE BIG BANG

Hawking got off to a flying start with his doctoral thesis, written at a critical time when there was a heated debate between two rival cosmological theories: the Big Bang and steady-state. Both theories accepted that the universe is expanding, but in the first it expands from an ultra-compact, super-dense state at a finite time in the past, while the second assumes the universe has been expanding forever, with new matter always being created to maintain a constant density. In his thesis, Hawking showed that steady-state theory is mathematically self-contradictory. He argued instead that the universe began as an infinitely small, infinitely dense point called a singularity. Today Hawking's description is almost universally accepted among scientists.



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PROVEN

BLACK HOLES ARE REAL

More than anything else, Hawking's name is associated with black holes – another kind of singularity, formed when a huge star undergoes complete collapse under its own gravity. These mathematical curiosities arose from Einstein's theory of general relativity, and they had been debated for decades when Hawking turned his attention to them in the early 1970s.

His stroke of genius was to combine Einstein's equations with those of quantum mechanics, turning what had previously been a theoretical abstraction into something that looked like it might actually exist in the universe. The final proof that Hawking was correct came in 2019, when the Event Horizon Telescope obtained a direct image of the supermassive black hole lurking in the centre of giant galaxy Messier 87.

PROVEN

HAWKING RADIATION

Black holes got their name because their gravity is so strong that photons – or particles of light – shouldn't be able to escape from them, rendering them dark. But in his early work on the subject, Hawking argued that the truth is more subtle than this monochrome picture.

By applying quantum theory – specifically the idea that pairs of 'virtual photons' can spontaneously be created out of nothing – he realised that some of these photons would appear to be radiated from the black hole. Now referred to as Hawking radiation, the theory was recently confirmed in a laboratory experiment at the Technion – Israel Institute of Technology in Haifa. In place of a real black hole, the researchers used an acoustic analogue: a 'sonic black hole' from which sound waves cannot escape. They detected the equivalent of Hawking radiation exactly in accordance with the physicist's predictions.

> "BY APPLYING QUANTUM THEORY, HE REALISED THAT SOME OF THESE PHOTONS WOULD APPEAR TO BE RADIATED FROM THE BLACK HOLE"

PROVEN

BLACK HOLE AREA THEOREM

In classical physics, entropy, or the disorder of a system that can only ever increase with time, never decreases. Together with Jacob Bekenstein, Hawking proposed that the entropy of a black hole is measured by the surface area of its surrounding event horizon.

The recent discovery of gravitational waves emitted by merging pairs of black holes shows that Hawking was right again. As Hawking explained to the BBC after the first such event in 2016: "The observed properties of the system are consistent with predictions about black holes that I made in 1970. The area of the final black hole is greater than the sum of the areas of the initial black holes." More recent observations have provided further confirmation of Hawking's area theorem.

TAP HERE TO PLAY

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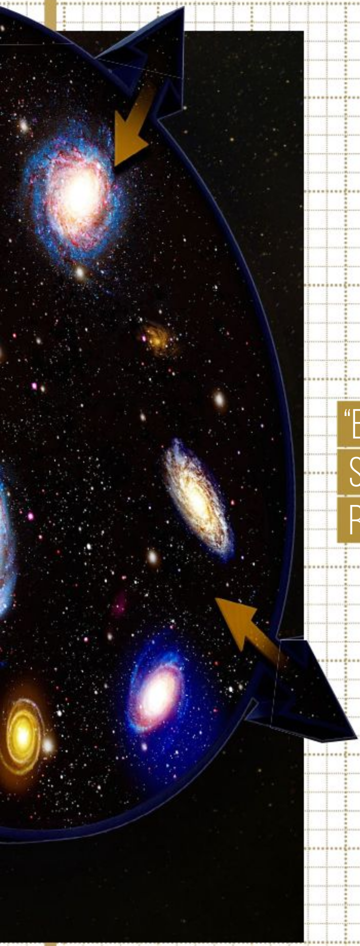


1970

With Penrose, he published a proof that the universe must have begun as a singularity.

1973

He published his first book, *The Large Scale Structure of Space-Time*, cowritten with George Ellis.

1974

He was elected a fellow of the Royal Society just weeks after the announcement of Hawking radiation.

1979

Elected Lucasian professor of mathematics at the University of Cambridge.

Stephen Hawking

1981

Proposed that information in a black hole is irretrievably lost when a black hole evaporates, igniting a 'black hole war' with Susskind and 't Hooft.

1984

First draft of *A Brief History of Time* completed, but the publisher thinks it's too technical.

1985

Contracted pneumonia and underwent a tracheotomy, losing his power of speech.

1988

A Brief History of Time was published. The book went on to sell 10 million copies.

1988

Together with Penrose, he won the Wolf Prize for physics, worth $100,000, "for their brilliant development of the theory of general relativity".

1989

Appointed a Companion of Honour in the Birthday Honours, but turned down a knighthood.

UNPROVEN

DOOMSDAY PROPHECIES

In his later years, Hawking made a series of bleak prophecies concerning the future of humanity that he may or may not have been totally serious about. These range from the suggestion that the elusive Higgs boson, or 'God particle', might trigger a vacuum bubble that would gobble up the universe to hostile alien invasions and artificial intelligence (AI) takeovers. Although Hawking was right about so many things, we'll just have to hope he was wrong about these.

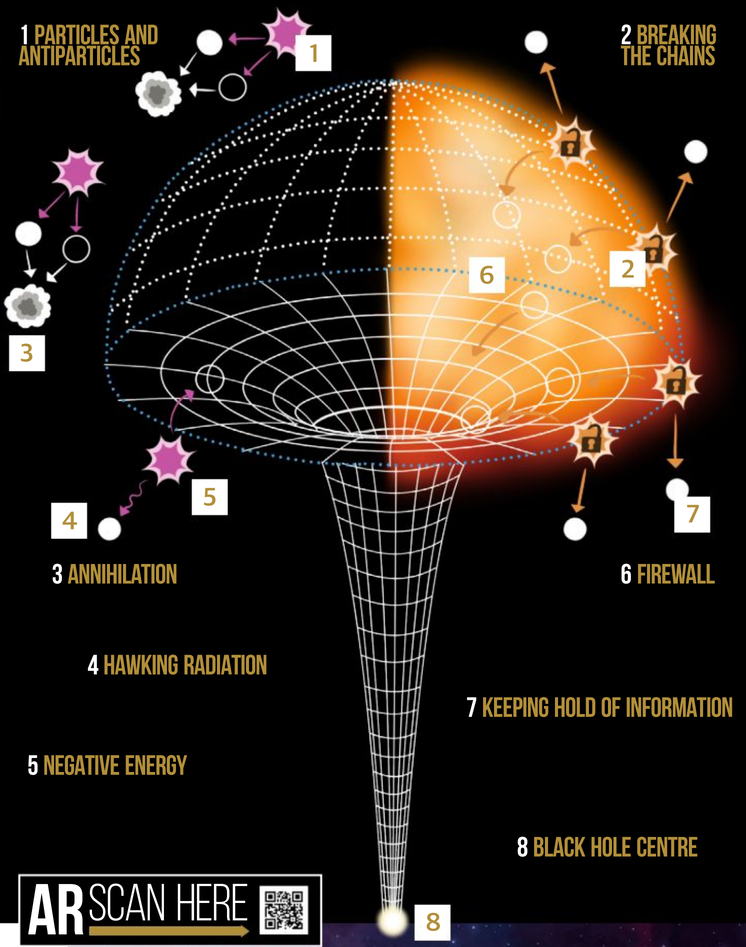
© Getty

PROVEN

THE INFORMATION PARADOX

The existence of Hawking radiation creates a serious problem for theoreticians. It seems to be the only process in physics that deletes information from the universe. The basic properties of the material that went into making the black hole appear to be lost forever – the radiation that comes out tells us nothing about them.

This is the so-called information paradox that scientists have been trying to solve for decades. Hawking's own take on the mystery, which was published in 2016, is that the information isn't truly lost. It's stored in a cloud of zero-energy particles surrounding the black hole, which he dubbed 'soft hair'. But Hawking's hairy black hole theorem is only one of several hypotheses that have been put forward, and to date no one knows the true answer.



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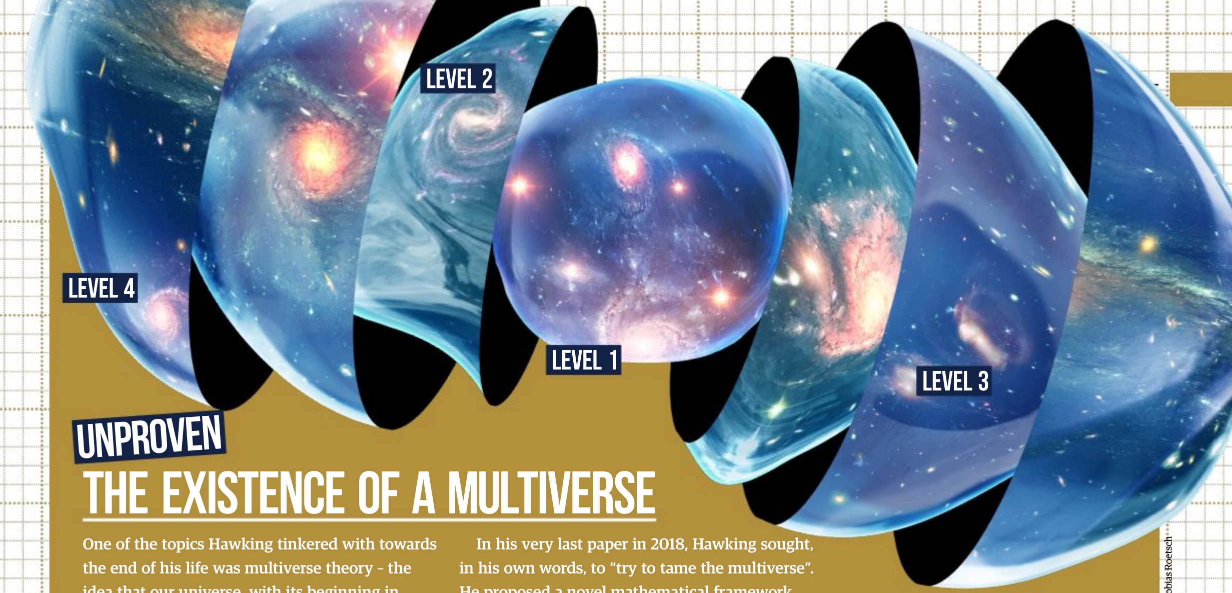

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UNPROVEN

THE EXISTENCE OF A MULTIVERSE

One of the topics Hawking tinkered with towards the end of his life was multiverse theory - the idea that our universe, with its beginning in the Big Bang, is just one of an infinite number of coexisting bubble universes. Hawking wasn't happy with the suggestion made by some scientists that any ludicrous situation you can imagine must be happening right now somewhere in that infinite ensemble.

In his very last paper in 2018, Hawking sought, in his own words, to "try to tame the multiverse". He proposed a novel mathematical framework that, while not dispensing with the multiverse altogether, rendered it finite rather than infinite. But as with any speculation concerning parallel universes, we have no idea if his ideas are right. And it seems unlikely that scientists will be able to test his idea any time soon.

> "HAWKING SOUGHT TO TRY TO TAME THE MULTIVERSE"

1991

A film version of *A Brief History of Time* premiered.

1997

A six-part documentary, *Stephen Hawking's Universe*, was made.

2004

Admitted he was on the wrong side in the 'black hole war', and bought Preskill an encyclopedia.

2005

Published *A Briefer History of Time* with Leonard Mlodinow to update his ideas and make them more accessible.

2007

Published *George's Secret Key to the Universe* with his daughter.

2009

Received the Presidential Medal of Freedom from Barack Obama.

2009

Held a party for time travellers, but none showed up.

2018

Hawking passed away.

UNPROVEN

PRIMORDIAL BLACK HOLES

Hawking was the first to explore the theory behind primordial black holes in depth. It turns out they could have any mass - though really tiny ones would have 'evaporated' into nothing by now due to Hawking radiation. One possibility considered by Hawking is that primordial black holes might make up the mysterious dark matter that astronomers believe permeates the universe. But current observational evidence indicates this is unlikely. Either way, we currently don't have observational tools to detect primordial black holes.

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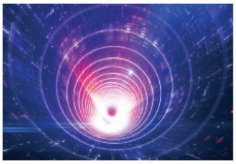
UNPROVEN

IS TIME TRAVEL POSSIBLE?

Surprising as it may sound, the laws of physics as we understand them today don't prohibit time travel. The solutions to Einstein's equations of general relativity include 'closed timelike curves', which would effectively allow you to travel back into your own past. Hawking was bothered by this because he felt that backward time travel raised logical paradoxes that shouldn't be possible. He suggested that some currently unknown law of physics prevents closed timelike curves from occurring - his so-called 'chronology protection conjecture'.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UNPROVEN

IS THERE A CREATOR?

One question cosmologists get asked most often is about what happened before the Big Bang. Hawking's own view was that the question is meaningless. For all intents and purposes, time itself - as well as the universe and everything in it - began at the Big Bang. "For me, this means that there is no possibility of a creator," he wrote in his final book, "because there is no time for a creator to have existed in." That's an opinion many people will disagree with, but one that Hawking expressed on numerous occasions throughout his life.

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PLANET PROFILE

NEPTUNE

The isolated azure giant remains a relative mystery

Neptune is the eighth planet from the Sun. It was the first planet to have its existence predicted by mathematical calculations before it was actually seen through a telescope on 23 September 1846. Irregularities in the orbit of Uranus led French astronomer Alexis Bouvard to suggest that the gravitational pull from another celestial body might be responsible. German astronomer Johann Galle then relied on subsequent calculations to help spot Neptune via telescope. Previously, astronomer Galileo Galilei sketched the planet, but he mistook it for a star due to its slow motion. In accordance with all the other planets seen in the sky, this new world was given a name from Greek and Roman mythology: Neptune, after the Roman god of the sea.

Only one mission has flown by Neptune – Voyager 2 in August 1989 – meaning that astronomers have done most studies using ground-based telescopes. Today there are still many mysteries about the cool, blue planet, such as why its winds are so speedy and why its magnetic field is offset. While Neptune is of interest because it is in our own Solar System, astronomers are also interested in learning more about the planet to assist with exoplanet studies. Specifically, some astronomers are interested in learning about the habitability of worlds that are somewhat bigger than Earth.

Those that are closer to Earth's size are called 'super-Earths', while those that are closer to Neptune's size are 'mini-Neptunes'. However, there's some debate about those terms given that today's telescope technology doesn't make it possible to view how much atmosphere is on those planet types, making it difficult to make a distinction. Like Earth, Neptune has a rocky core, but it has a much thicker atmosphere that prohibits the existence of life as we know it. Astronomers are still trying to figure out at what point a planet becomes so large that it may pick up a lot of gas from the area, making it difficult or impossible for life to exist.

Neptune's cloud cover has an especially vivid blue tint that is partly due to an as-yet-unidentified compound and the result of the absorption of red light by methane in the planet's mostly hydrogen-helium atmosphere. Photos of Neptune reveal a blue planet, and it's often dubbed an ice giant, since it possesses a thick, slushy fluid mix of water, ammonia and methane ices under its atmosphere. It is roughly 17 times Earth's mass and nearly 58 times its volume. Neptune's rocky core alone is thought to be roughly equal to Earth's mass.

Despite its great distance from the Sun, which means it gets little sunlight to help warm and drive its atmosphere, Neptune's winds can reach up to 2,400 kilometres (1,500 miles) per hour – the fastest detected yet in the Solar System. These winds were linked with a large, dark storm that Voyager 2 tracked in Neptune's southern hemisphere in 1989. This oval-shaped, counterclockwise-spinning 'Great Dark Spot' was large enough to contain the entire Earth, and moved westward at nearly 1,200 kilometres (750 miles) per hour. This storm seemed to have vanished when the Hubble Space Telescope later searched for it. Hubble has also revealed the appearance and then fading of other dark spots over the past decade, and a new one was observed in 2016. It doesn't look like Neptune is finished with surprising scientists just yet.

© NASA/JPL-Caltech

Left: A Voyager 2 view of Neptune

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> “TODAY THERE ARE STILL MANY MYSTERIES ABOUT THE COOL, BLUE PLANET, SUCH AS WHY ITS WINDS ARE SO SPEEDY”

ATMOSPHERIC COMPOSITION

80%
HYDROGEN

19%
HELIUM

1.5%
METHANE

OVERALL COMPOSITION

25%
ROCK

60-70%
ICE

5-15%
HYDROGEN AND HELIUM

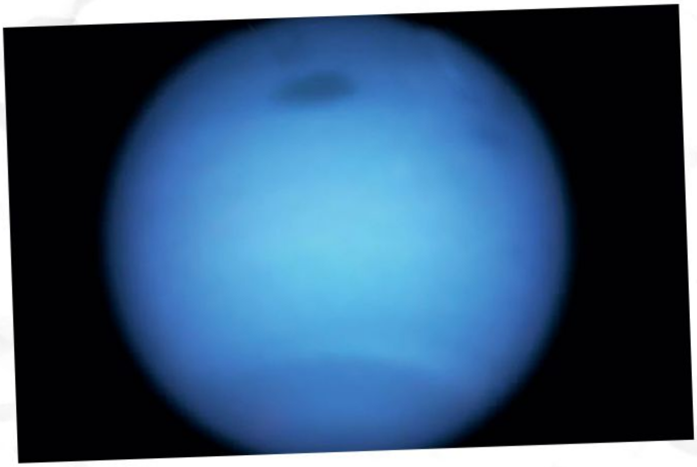
© Getty

NEWS FROM NEPTUNE

A dark storm on Neptune mysteriously reversed

A dark storm on Neptune abruptly switched direction and started moving away from almost certain death, puzzling astronomers. NASA's Hubble Space Telescope first spotted the vortex in 2018. A year later, the storm began drifting southward towards Neptune's equator, following the path of several storms before it. Usually these dark spots on Neptune live for a few years before either vanishing or fading away. However, the storm mysteriously stopped moving south and made a sharp U-turn, drifting back northwards. At the same time, astronomers spotted a second, smaller dark spot on the planet. They theorise that this smaller 'cousin' may be a piece of the original vortex that broke off and drifted away.

Although Hubble has tracked similar storms on Neptune over the past 30 years, astronomers have never seen such unpredictable atmospheric behaviour. The 2018 storm, which was 7,403 kilometres (4,600 miles) across, is the fourth-darkest spot Hubble has tracked since 1993.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Neptune's smallest moon has a violent past

Hippocamp is believed to have a diameter of about 34 kilometres (21 miles). The tiny moon circles in the same general neighbourhood as six moons discovered by Voyager 2 during the probe's flyby of Neptune in 1989. Hippocamp is just 12,000 kilometres (7,450 miles) inland to the largest and outermost of these other six, Proteus.

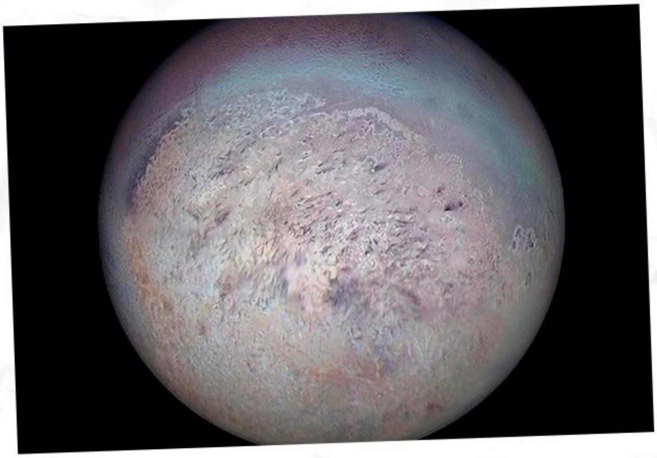
Like Earth's Moon, Proteus has been slowly spiralling away from its parent planet. So has Hippocamp, though at a much slower rate. About 4 billion years ago, Proteus was probably right next to Hippocamp and would have gobbled the smaller moon up. Scientists believe that Hippocamp was once part of its larger neighbour and likely coalesced from pieces of Proteus that were blasted into space by a long-ago comet impact.

Neptune's moon Triton has a rare kind of ice

Neptune's largest moon Triton boasts an uncommon icy mixture of carbon monoxide and nitrogen, which could help astronomers better understand the conditions of other distant alien worlds.

Using the Gemini Observatory in Chile and a high-resolution spectrograph called the Immersion Grating Infrared Spectrometer (IGRINS), a visiting instrument for Gemini, astronomers detected a distinct infrared signature on Triton, revealing a mixture of carbon monoxide and nitrogen frozen as solid ice. This finding helps explain seasonal atmospheric changes on Triton and how material is transported across the moon's surface via geysers.

The icy mixture detected on Triton could help explain the moon's iconic geysers, which are the dark, windblown streaks first observed by NASA's Voyager 2 spacecraft in the moon's south polar region. These distinct streaks are believed to be erupted material from an internal ocean, or an icy mixture that migrates around the surface in response to changing seasonal patterns of sunlight.


© NASA/JPL

WHEN TRITON CRASHED THE PARTY AT NEPTUNE

Neptune's original satellites may have been destroyed when its largest moon, Triton, entered the picture. The massive moon may have tossed some of the original satellites into the ice giant, kicked others out of orbit and swallowed up the rest, creating a new family that doesn't look much like those of other giant planets.

For years scientists have suspected that Triton wasn't part of Neptune's original collection of moons. The massive moon has a backward orbit and makes up over 99 per cent of all the mass orbiting the planet. They think it's a captured object whose orbit was circularised by debris discs created by impacts.

The moons of Jupiter, Saturn and Uranus are all well-behaved compared with Neptune's. The other three gas giants have a wealth of satellites – Jupiter has 79 to Neptune's 14 – travelling in nearly circular paths around their equators. While Triton's path is circular, it travels backwards compared with Neptune's rotation, and spins backwards too.

© NASA

EVOLUTION OF NEPTUNE

- **Date:** 23 September 1846
  Activity: Astronomer Johann Gottfried Galle viewed Neptune through a telescope for the first time
- **Date:** 10 October 1846
  Activity: Neptune's largest moon Triton was discovered
- **Date:** 25 August 1989
  Activity: NASA's Voyager 2 flew by Neptune and came within just 3,000 kilometres (1,860 miles) of the planet's north pole
- **Date:** 1 July 2013
  Activity: Neptune's smallest moon S/2004 N1 was discovered during an analysis of older Hubble images
- **Date:** 8 October 2013
  Activity: Neptune's 'lost' moon Naiad was spotted for the first time in 20 years. The tiny moon had remained unseen since the cameras on NASA's Voyager 2 spacecraft first discovered it in 1989.

NEPTUNE BY NUMBERS

165 EARTH YEARS
How long Neptune takes to complete an orbit of the Sun

-214°C
Average temperature on Neptune

14
The number of known moons of Neptune

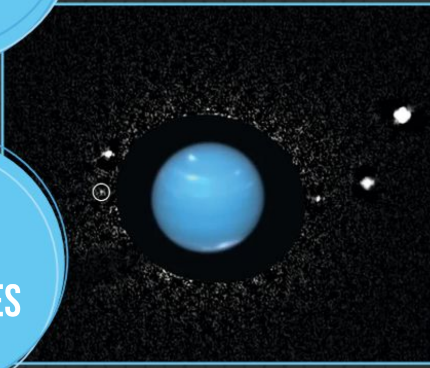
28.3°
The angle of Neptune's tilt as it orbits the Sun

4.5 BILLION KILOMETRES
How far Neptune is from our Sun

7.6 BILLION SQUARE KILOMETRES
The surface area of Neptune

27x
How many times more powerful Neptune's magnetic field is than Earth's.

16 HOURS
The length of a day on Neptune



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> "SCIENTISTS SUSPECTED TRITON WASN'T PART OF NEPTUNE'S ORIGINAL COLLECTION OF MOONS"

WATER VAPOUR DETECTED ON HUGE JUPITER MOON GANYMEDE FOR THE FIRST TIME

This could be a trend for icy bodies throughout the Solar System and beyond

Reported by Charles Q. Choi

© Getty

In the wisp-thin sky of Ganymede, the largest satellite in the Solar System, astronomers have detected evidence of water vapour for the first time. The discovery could shed light on similar watery atmospheres that may envelop other icy bodies in the Solar System and beyond.

Research has suggested that Ganymede – which is larger than Mercury and Pluto and only slightly smaller than Mars – may contain more water than all of Earth's oceans. However, the Jovian moon is so cold that water on its surface is frozen. Any liquid water would lurk about 160 kilometres (100 miles) below its crust.

Prior work suggested that ice on Ganymede's surface could turn from a solid directly to a gas, skipping a liquid form entirely, so that water vapour could form part of the giant moon's thin atmosphere. However, evidence of this water has proved elusive... until now.

In a new study, researchers analysed old and new data of Ganymede from NASA's Hubble Space Telescope. In 1998 Hubble captured the first ultraviolet images of Ganymede, including pictures of its aurorae, the giant moon's versions of Earth's northern and southern lights. Colourful ribbons of electrified gas within these aurorae helped provide evidence that Ganymede has a weak magnetic field.

Ultraviolet signals detected in these auroral bands suggested the presence of oxygen molecules, each made of two oxygen atoms, which are produced when charged particles erode Ganymede's icy surface. However, some of these ultraviolet emissions didn't match what you would expect from an atmosphere of pure molecular oxygen. Previous research suggested these discrepancies were linked to signals from atomic oxygen – single atoms of oxygen.

As part of a large observing program to support NASA's Juno mission, researchers sought to measure the amount of atomic oxygen in Ganymede's atmosphere using Hubble. Unexpectedly, they discovered there is hardly any atomic oxygen there, suggesting there must be another explanation for the earlier ultraviolet signals. The scientists focused on how the surface temperature of Ganymede varies strongly throughout the day, with highs of about -123 degrees Celsius (-190 degrees Fahrenheit) at noon at the equator and lows of about -193 degrees Celsius (-315 degrees Fahrenheit) at night.

At the hottest spots on Ganymede, ice may become sufficiently warm enough to convert directly into vapour. They noted that differences seen between a number of ultraviolet images from Ganymede closely match where you would expect water in the moon's atmosphere based on its climate.

"Water vapour in the atmosphere matches the data very well," study lead Lorenz Roth, a planetary scientist at the KTH Royal Institute of Technology in Stockholm, said. The main reason previous research failed to detect water in Ganymede's atmosphere is because the ultraviolet signal from molecular oxygen is very strong. "Within this stronger oxygen signal, it's hard to find other signals," Roth said. "These findings suggest that water vapour actually exists in the atmospheres of icy bodies in the outer Solar System," he continued. "Now we might see it in more places."

Left: Ganymede is Jupiter's largest moon, but only seventh-closest to the giant planet

"FINDINGS SUGGEST WATER VAPOUR ACTUALLY EXISTS IN THE ATMOSPHERES OF ICY BODIES IN THE SOLAR SYSTEM"

LORENZ ROTH

MYSTERIES OF THE UNIVERSE

WHAT LIT UP THE SKY IN 1054?

The Crab Nebula was formed by a supernova, and astronomers now think they know which type caused it

Reported by David Crookes

In 1054 CE, Chinese astronomers looked towards the sky and discovered a star which had suddenly appeared in a position 6,500 light years away where no star had previously been observed. They watched as it shone six times more brightly than Venus in the constellation of Taurus for 23 days from 4 July, and their observations were backed by astronomers in Japan and the Arab world.

Reported as a 'guest star' by the chief of the astronomical bureau at K'ai-feng, it remained visible until 17 April 1056. It would then be another 872 years before Edwin Hubble became the first to associate the observation with another discovery - that of the Crab Nebula, which was spotted in 1731 by English astronomer John Bevis.

Hubble suggested that what the Chinese astronomers had seen was a supernova explosion that had caused stellar remains to be scattered across an area of space some six light years wide. It was a controversial theory, primarily because the study of supernovae was still in its infancy. But in 1939, American observational astronomer Nicholas Mayall demonstrated beyond doubt that the two were linked.

Having established that the 'guest star' of 1054 was a supernova - a term first used in the 1930s by Walter Baade and Fritz Zwicky at Mount Wilson Observatory - astronomers had many questions. Was the date of the explosion correct, for instance, and were reports of the celestial fireworks consistent. In those cases, possibly yes and not entirely are found to be the general answers.

"If you watch the remnant expand today and work out when all that material was back together, the answer comes out to be 1054," affirms Andy Howell, a staff scientist at Las Cumbres Observatory. "The position is also roughly consistent with the reports from Chinese astronomers, although they said it was 'to the southeast of Tianguan [Taurus], perhaps several inches away' when it's actually to the northwest." The biggest question, however, was whether

© Tobias Roetsch

ELECTRON-CAPTURE SUPERNOVAE BY NUMBERS

8-10x

Progenitor is eight to ten times more massive than the Sun

2018

Year SN 2018zd was first detected

31,000,000

Distance of SN 2018zd, in light years, from Earth

TWO

Supernovae observed so far: SN 2018zd and SN 1054

967

Years since SN 1054 was observed

23

Number of days SN 1054 was shining bright

1980

The year Nomoto predicted electron-capture supernovae

SIX

Theorised indicators of an electron-capture supernova

200

Number of people involved in the Global Supernova Project

1731

Year the Crab Nebula was first identified

SN 1054, as it became known, was a Type Ia or Type II supernova. And this would be a good time to recap the difference between the two.

Type Ia is also known as a thermonuclear supernova, and it occurs when a star of up to eight solar masses in a binary star system dies and becomes a dense white dwarf. The dwarf's strong gravity begins to siphon material from its companion star, and when its mass gets close to the Chandrasekhar limit, it begins to shrink under the weight and becomes unstable. A star made of carbon and oxygen undergoes a runaway fusion, exploding it.

Type II supernovae, on the other hand, are caused by the death of a massive star - greater than ten solar masses - as it runs out of fuel and collapses in on itself, a reason why they're also called iron core-collapse supernovae. This demise releases large quantities of energy and leaves behind either a dense neutron star or a black hole. So which type was SN 1054? The event fits within the realm of a Type II because the Crab Nebula has a pulsar - a spinning neutron star - at its centre. Yet the ejecta in the remnant is moving slowly, indicating low kinetic energy.

"It didn't produce very much radioactive 56Ni [nickel], and the chemical signature of the ejecta is strange," says Howell. "There's also about five solar masses of material in the ejecta because some of it went into the making of the neutron star and some was lost earlier in the star's life." This actually points to a different type of supernova - one proposed in 1980 by Japanese physicist Ken'ichi Nomoto of the University of Tokyo. The problem? Nobody has ever discovered another supernova that could fit Nomoto's theory in a convincing or conclusive way… at least until now.

Howell is the leader of the Global Supernova Project, a three-year program to obtain light curves and spectra for 500 supernovae. He's one of many scientists contributing to a study led by Daichi Hiramatsu, also of Las Cumbres Observatory. They have discovered the very first evidence that points to the existence of an electron-capture supernova, the type that Nomoto has advocated for 40 years.

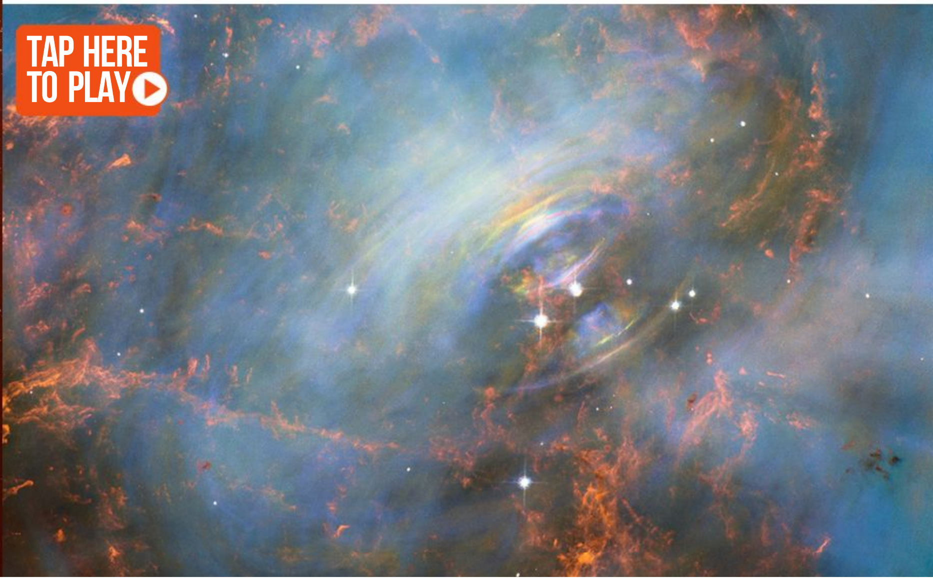
According to Nomoto, electron-capture supernovae sit in between Type Ia and Type II, with the progenitor star being about eight to ten times the mass of the Sun. The star is not light enough to prevent its core from collapsing, and it's not heavy enough to go the way of a Type II. The star also experiences excessive mass loss before the supernova explosion, resulting in the circumstellar material with an odd composition. The supernova explosion produces little radioactivity and low kinetic energy. The core needs to contain neutron-rich elements, too, which means it has more stable nickel compared to radioactive nickel.

"I think that Nomoto and his team came up with the theory independent of SN 1054, but realised soon after that it might explain the Crab Nebula," Howell says. "He wrote a *Nature* paper about it in 1982 that was a big deal, and he's been talking about it ever since, at almost every supernova conference."

Howell says many others have since added to the discussion, "especially Nathan Smith, who had a great paper in 2013 adding more evidence that SN 1054 could be an electron-capture supernova". But while the Crab Nebula fits many expectations of electron-capture supernovae, some natural questions were going unanswered. "Why was it brighter than expected?" Howell quizzes. And crucially: "Why haven't we seen a supernova

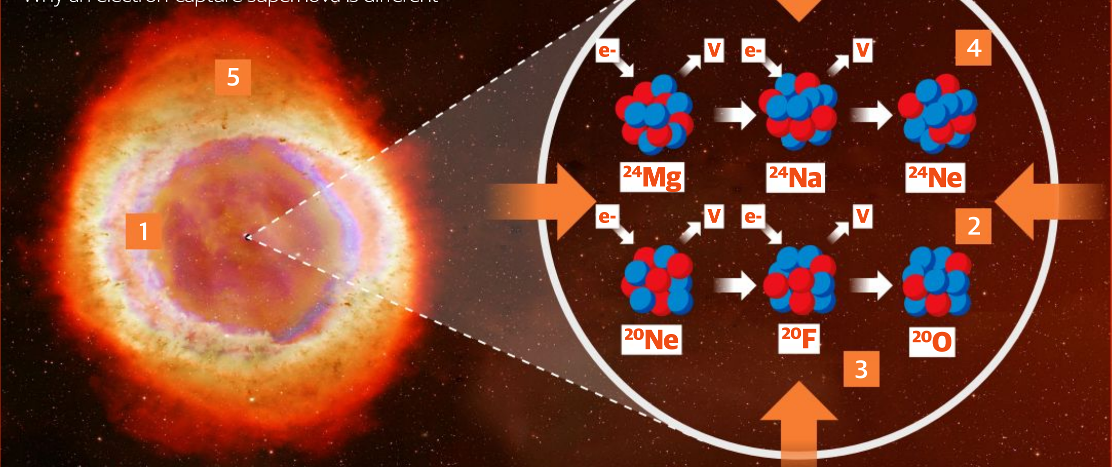
Below: A composite image of the Crab Nebula - a remnant of the supernova SN 1054

Right: Andy Howell is a staff scientist at Las Cumbres Observatory and leader of the Global Supernova Project



WHEN STARS EXPLODE

Why an electron-capture supernova is different



1 MASS RANGE OF ELECTRON-CAPTURE SUPERNOVAE

Howell says astronomers aren't sure of the exact mass range for electron-capture supernovae, but it's larger than Type Ia and smaller than Type II supernovae: "It could be anything in between eight and ten solar masses."

2 OXYGEN AND NEON

An electron-capture supernova needs a core made of oxygen, neon and magnesium, and that's why it has to be between eight and ten solar masses. "Heavier stars make iron cores, and lighter ones make carbon-oxygen cores," Howell explains.

3 FUSION STOPS

Ongoing fusion prevents a star from collapsing. If fusion has ceased, then the star won't collapse if the atoms cannot be any more tightly packed. In electron-capture supernovae, fusion stops but some electrons in the core smash into their atomic nuclei.

4 REMOVAL OF ELECTRONS

The collisions cause electrons to be removed by the neon and magnesium, and the core of the star collapses under its own weight. This causes a stellar explosion. "The star can't have too much mass loss before it explodes," says Howell.

5 SHINING BRIGHT

SN 2018zd – just like SN 1054 – shone brightly, and that has been explained by the likelihood that matter ejected from the explosion collided with circumstellar material being cast off by the progenitor star.

© Tobias Roetsch

in real life with the properties of an electron-capture supernova?"

Back in 2018 those questions could finally be answered, since in March of that year Japanese amateur astronomer Koichi Itagaki discovered a new supernova roughly 31 million light years away in the galaxy NGC 2146. It caught the attention of researchers because it was nearby and bright, and they were able to use their global network of telescopes, as part of the Global Supernova Project, along with other facilities such as NASA's Swift satellite, the Hubble Space Telescope and the Keck Observatory to examine it further.

"Daichi, a graduate student working with me, noticed that this supernova – which came to be called SN 2018zd – had some unusual properties that we'd never seen in a supernova before, like really strange colours just after the explosion," says Howell. "After a few months, the supernova's brightness dropped like a rock – the largest drop we'd ever seen. It indicated there wasn't much radioactive material produced in the supernova." As with every nearby supernova, the team checked to see if the Hubble Space Telescope had observed its galaxy before. "We were hoping it might have a prior image of the star before it exploded," Howell explains. "We found a few images, but the star was only visible in one of them, in the infrared. If the star would have been a red supergiant – the progenitors of normal core-collapse supernovae – we would have seen it in more filters.

"However, the detection was consistent with the properties seen in another star in the Milky Way suspected of being a super-asymptotic giant branch star, which are thought to be the progenitors of electron-capture supernovae."

© UCSB

Indeed, it soon became apparent that SN 2018zd was the only supernova ever detected to have all six of the characteristics said to form an electron-capture supernova. Just as importantly, the astronomers were also able to use the study of SN 2018zd to answer some of the questions they had about SN 1054.

Up until that point, they were only part certain that an electron-capture supernovae had resulted in the Crab Nebula. "It has the right chemical composition of the ejecta, it has low kinetic energy and it produces neutron-rich elements, but we don't know anything about the progenitor since it exploded and was only around before telescopes were invented," Howell explains.

What astronomers had done in their studies of SN 1054, however, was reconstruct a rough light curve based on brightness comparisons to other

© NASA

> “NOW WE HAVE GOOD EVIDENCE FOR ELECTRON-CAPTURE SUPERNOVAE, WE CAN REVISIT THOSE QUESTIONS”
>
> ANDY HOWELL

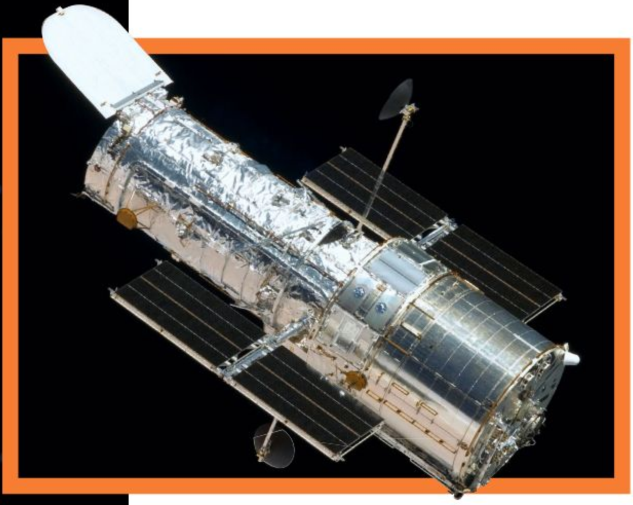
© Tobias Roetsch

Above: This Hubble image captures the beating heart of the Crab Nebula – a rapidly spinning pulsar

Left: A star would need to be at least eight times heavier than our Sun to create this special type of supernova explosion

stars and the Moon and the observation that the ‘guest star’ had been visible during the day for 23 days, finding it had an apparent magnitude of -6.0. This light curve had been suggested to be too bright for an electron-capture supernova. “But if we infer that there was a lot of circumstellar material cast off by the progenitor, just as there was in SN 2018zd, the interaction of the supernova ejecta and that material may have brightened the light curve.” It would seem that there really are electron-capture supernovae, but what significance does this have?

“Before that we knew the distribution of pulsars was bimodal – some with short spin periods and some with longer spin periods,” says Howell. “It was also speculated that maybe the short-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spin-period systems came from electron-capture supernovae. There's a similar bimodality in the neutron star sizes: there's a peak in the neutron star mass distribution at 1.3 solar masses, and another at 1.5 solar masses.

"Some have speculated that the low-mass neutron stars come from electron-capture supernovae. Now that we have good evidence for electron-capture supernovae, we can revisit those questions. And since we also have direct evidence that supernovae produce more neutron-rich material, it tells us more about how these elements are produced in nature."

Studies of SN 2018zd are set to continue. For starters, the astronomers want to be sure the distance to the host galaxy is correct. "It's rather uncertain," says Howell. Fresh observations of the galaxy will be undertaken using Hubble to nail down the distance to confirm how bright SN 2018zd is. "We tried to do most of the analysis in a distance-independent way because of this," Howell explains.

"We also need to find more electron-capture supernovae," he continues. "They look enough like normal supernovae that we might have been confused before. There was also speculation that a small class of supernovae called SNe IIn-P might be electron-capture supernovae, and that might be correct.

"Now that we know what they look like, we can reanalyse old data, and knowing the fraction of supernovae that they make up will help us narrow down the progenitor mass range. The observations may lead to new theoretical studies as well, now the theorists know better which aspects of their predictions are realised in nature." In that sense, the findings around SN 2018zd really are proving to be a 'eureka' moment.

After all, the discovery and subsequent study of SN 2018zd is helping astronomers find out more about the Crab Nebula, something we're still a way off fully understanding, and it's also helping to shed fresh light on what happened nearly 1,000 years ago. Howell says SN 2018zd is letting us discover more about how some neutron stars are made and how extreme stars live and die, too. "It is very exciting indeed," he concludes.

Above: When SN 2018zd was observed, scientists were able to examine archive images taken by Hubble to detect the likely progenitor

David Crookes

Science and technology journalist

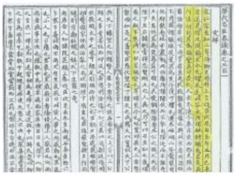
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

HOW SN 1054 HAS BEEN EXPLAINED

A few theories have emerged over the years

A 'GUEST STAR'

Chinese astronomers who observed what we know to be SN 1054 today referred to it as a 'guest star' because it appeared, faded and disappeared. It had "pointed rays in every direction," according to records of the Song dynasty, and it was "reddish white". It is not mentioned in any European records.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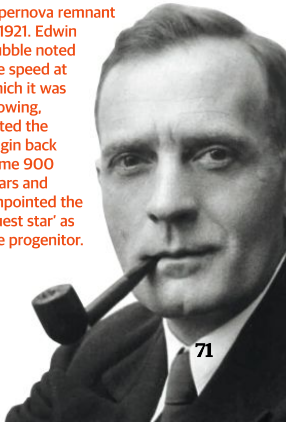
AN ELECTRON-CAPTURE SUPERNOVA EVENT

Having established SN 1054 as a supernova – hence its name – astronomers sought its true nature. In 1980, Nomato proposed an electron-capture supernova. SN 1054 was suspected to be of this type, and the latest research provides more evidence to support this.

© Getty

A STELLAR EXPLOSION

The Crab Nebula was discovered by English astronomer John Bevis in 1731. It was speculatively identified as a supernova remnant in 1921. Edwin Hubble noted the speed at which it was growing, dated the origin back some 900 years and pinpointed the 'guest star' as the progenitor.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COULD WE HUNT FOR GRAVITATIONAL WAVES FROM THE MOON?

Such an observatory could unlock the cosmos' secrets

Reported by Mike Wall

NASA is working to establish a permanent human presence on and around the Moon by the end of the 2020s via a program known as Artemis. That presence may eventually include radio telescopes on the Moon's exceptionally quiet far side, and perhaps even more ambitious off-Earth science facilities.

A recent study makes the case for building a gravitational-wave observatory on the Moon. Gravitational waves are ripples in space-time created by massive objects. They were predicted by Einstein's general theory of relativity in 1915, and first directly detected a century later by the Laser Interferometer Gravitational-Wave Observatory (LIGO) consortium.

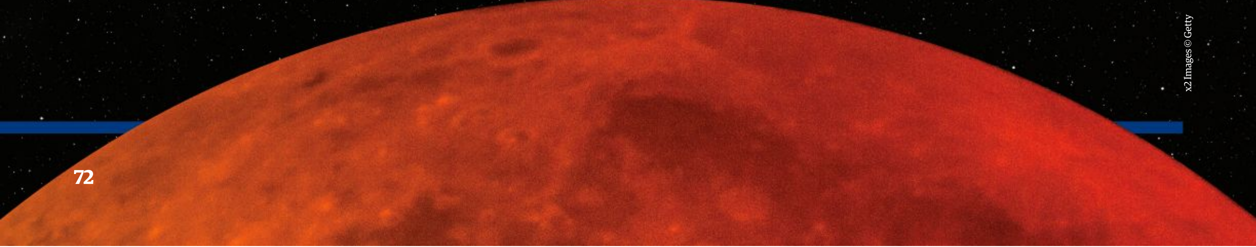
LIGO has detectors at two sites in the US: one in Louisiana and one in Washington. Each detector is an L-shaped structure with arms four kilometres (2.5 miles) long, with a laser at the centre of the array. The laser shines light down each arm, and mirrors reflect the light back. If the light from one arm is beamed back a little late, it's evidence of a possible gravitational-wave-induced distortion.

The LIGO team has detected dozens of gravitational-wave events to date, most of them caused by mergers between two black holes. But this is exacting work, and our noisy, active Earth makes spotting signals tough. The Moon, on the other hand, is an exceptionally quiet place.

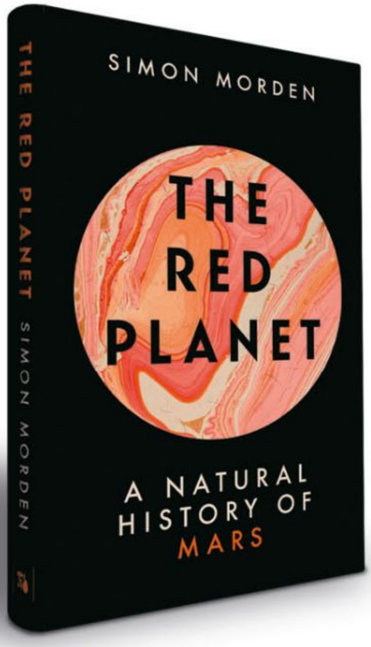
"The Moon offers an ideal backdrop for the ultimate gravitational-wave observatory since it lacks an atmosphere and noticeable seismic noise, which we must mitigate at great cost for laser interferometers on Earth," said Avi Loeb, an astronomer at Harvard University. "A lunar observatory would provide unprecedented sensitivity for discovering sources that we do not anticipate and that could inform us of new physics. GLOC could be the jewel in the crown of science on the surface of the Moon."

'GLOC' is short for the Gravitational-wave Lunar Observatory for Cosmology, the name Loeb and Karan Jani propose for the Moon facility. GLOC would be huge compared to LIGO and other detectors on Earth, featuring arms 40 kilometres (25 miles) long. And it would be incredibly sensitive, capable of spotting gravitational-wave events in nearly 70 per cent of the observable volume of the universe.

GLOC is just an idea at the moment, but Loeb and Jani say they hope to develop a pathfinder mission on the Moon that would test required technologies in the coming years. And if GLOC – or something like it – does end up getting built, it will pay scientific dividends for decades to come.



x2 Images © Getty



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ASK Space

Our experts answer your questions

Above: Science has evolved so much that we can now image a black hole's shadow

© EHT Collaboration

ASTROPHYSICS

Are we finally getting a better understanding of black holes?

Hugely so. Ten years ago, you could still make an argument that maybe black holes aren't real - they're just a figment of mathematics. But with LIGO [the Laser Interferometer Gravitational-Wave Observatory], the collision of two black holes giving that first ripple in the fabric of space, and with the Event Horizon Telescope - even the Nobel Prize this year was awarded to work on black-hole physics - black holes have come into their own. For someone like me who works on cutting-edge theoretical ideas, we're struggling now to merge black holes and quantum mechanics to get a full understanding. Black holes are the prime theoretical laboratory for pushing our ideas to the limit. When we can fully understand black holes and quantum mechanics, I suspect our understanding of the universe is going to jump to a whole new level.

© Getty

Brian Greene, theoretical physicist and science populariser

SPACE EXPLORATION

How did your spaceflight experiences change you? What were the best or most memorable parts?

Right: Melvin on board Space Shuttle Atlantis, during November 2009's STS-129 mission

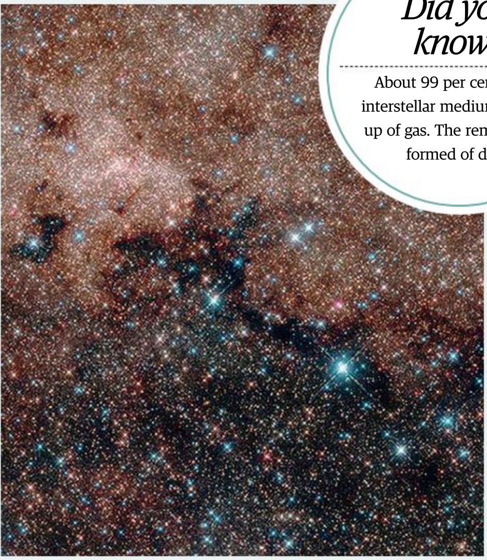
x2 images © NASA

There are so many unforgettable aspects of life in space, including the experiments, the robotics and the spacewalks, but I think my most memorable moment took place when Peggy [Whitson, commander of the space station's Expedition 16] and her crew invited us to have dinner over in the service module. "You guys bring the vegetables, we'll bring the meat," they said, and we all congregated around the small table, with some floating above and others below. There we were, French, German, Russian, Asian American, African American, all having a meal in space.

Out the window we could see Afghanistan, Iraq and other troubled spots. Some 240 miles [386 kilometres] above those strife-torn places, we sat in peace with people we once counted among our nation's enemies, bound by a common commitment to explore space for the benefit of all humanity. It was one of the most inspiring moments of my life. That day I gained a newfound perspective on how it's possible for different people to live and work together - definitely needed to bring that hope and optimism back home to Earth.

Leland Melvin, former NASA astronaut and engineer

> "WE SAT IN PEACE WITH PEOPLE WE ONCE COUNTED AMONG OUR ENEMIES"
>
> LELAND MELVIN



Left: There's so much space between stars that collisions are rare

© NASA, ESA, and Hubble Heritage Team

Did you know?

About 99 per cent of the interstellar medium is made up of gas. The remainder is formed of dust.

COSMOLOGY

How does the interstellar medium help form stars?

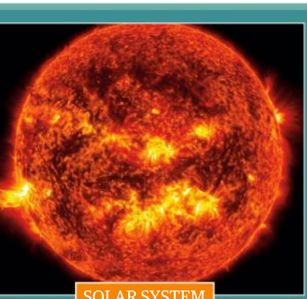
The material which fills the space between stars provides the raw materials for new stars to be born. It's mostly hydrogen, some helium and a tiny amount of dust particles. Within the interstellar medium, there are clouds of varying densities that are rich in molecules like hydrogen and carbon monoxide. These molecular-rich gas and dust clouds provide the ingredients that ultimately make up the building blocks of stars. In the densest regions of the interstellar medium, the core collapse of such a cloud can be triggered by a shock wave.

These shock waves can be caused by a nearby supernova, by a collision with another molecular cloud or even by passing through the spiral arm of a galaxy, like our Milky Way. Such a shock wave can cause the rapid infall of the molecular material to produce the core of a new star, which continues to accrete as the star is born. These regions in the interstellar medium are stellar nurseries in the cosmos and are critical to the cycle of the life of a star.

Dr Emily Rickman, research fellow in astronomy at the European Space Agency

ASK Space

Our experts answer your questions



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SOLAR SYSTEM

How is space weather predicted?

The Sun and interplanetary space are monitored for notable changes in solar-related phenomena that can provide forecasters clues about the chances of space weather storms.

Space weather generally refers to activity on the Sun, in the large vacuum of space between Earth and the Sun and ultimately here at and around Earth. The Space Weather Prediction Center (SWPC) in Boulder, Colorado, is continuously staffed – 24 hours every day – to monitor space weather and provide daily forecasts. The SWPC also issues warnings and alerts about substantial space weather storms and events, because they may impact technologies we rely upon today.

The Sun goes through an 11-year cycle whereby solar activity is less common (solar minimum) and more frequent (solar maximum). We are now heading towards solar maximum over the next several years, so not only will solar activity increase, but strong space weather storms will become more probable. Visit **swpc.noaa.gov** for all sorts of current space weather information and forecasts.

Shawn Dahl, space weather forecaster for the Space Weather Prediction Center

Left: Solar storms can damage electronics on Earth

Right: Debris poses a serious problem in space – but who is responsible?

© NASA/ESA

SPACE EXPLORATION

Who is responsible for falling space debris?

Space is an area beyond national jurisdiction. Like the high seas, space is governed through international law. The 1967 Outer Space Treaty and four other international space treaties that followed set out a framework and key principles to guide responsible behaviour. The 1972 Liability Convention specifies a compensation regime that would apply in many circumstances of damage caused by space debris falling to Earth, as well as when satellites collide in space.

This legal regime imposes liability on 'launching states' for damage caused by their space objects, which includes an absolute liability regime when they crash to Earth as debris. The liability under international space law is therefore imposed on countries, even where the space object or debris that causes the damage is privately owned and/or operated. The Liability Convention has only been previously invoked once – for the Kosmos 954 incident of 1978 – and therefore may not be regarded as a powerful disincentive. However, it is likely to come into play in the future in a more crowded space environment, and with more uncontrolled re-entries. Of course, this legal framework applies only after the damage occurs.

In addition, there are other regulatory 'rules of the road' that deal with space governance agreed through the United Nations Committee on the Peaceful Uses of Outer Space, including practical guidelines for debris mitigation and long-term sustainability of space activities.

In reality, a globally coordinated space traffic management system will also be vital to avoid collisions that would result in loss of control of satellites, leaving them to tumble helplessly in orbit or fall back to Earth.

Steven Freeland, director of the International Institute of Space Law

COSMOLOGY

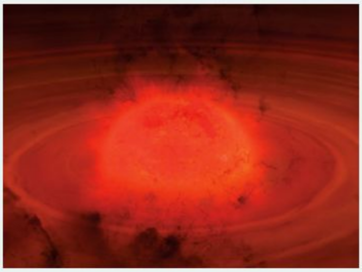
Why do discs form around protostars?

Many processes play a role in disc formation, but angular momentum is the principal quantity. The protostar and its disc are formed from the same cloud composed of gas and dust, which initially has some rotation – it has angular momentum, which is a measure of the direction and speed that something is rotating. The cloud collapses due to its own gravity. However, angular momentum hinders this process, and the cloud collapses into a rotating 'pancake' rather than a sphere. If the central region contains enough dense gas, then a rotating protostar will form.

The gas and dust surrounding the new star continues to rotate. The amount of angular momentum that this gas and dust contains is one of the primary quantities that will determine its fate. If there is too little angular momentum, then the gas and dust will fall onto the star and increase its mass. However, if there's enough angular momentum then the gas and dust will remain as a rotationally supported protostellar disc. At a large enough distance from the protostar, the orbiting gas and dust will no longer be rotationally supported, indicating the outer edge of the disc. This edge is reasonably well defined, making the disc distinct from its surroundings.

Dr James Wurster, research fellow, University of St Andrews

Right: The protostellar disc's extra material can form planets



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SPACE EXPLORATION

How important is astrobotany research for future space exploration efforts?

Did you know?

Three types of lettuce, Chinese cabbage, mizuna mustard and red Russian kale have been grown on the ISS.

Astrobotany is going to be critical for future space exploration, particularly in the realm of providing caloric support for extended spaceflight missions. In the near future, it's unlikely we will use plants as an oxygen source in a bioregenerative life-support system (BLSS) because gas exchange is more easily controlled manually than relying on plants to produce enough oxygen to support a crew. The science is not precise or reliable enough to depend on just plants for oxygen. However, it will be of huge benefit to supplement caloric intake with plants in space.

The sustainability of harvesting in space is another perk that cannot go overlooked. Resupplies to the International Space Station (ISS) are necessary, but resupplies beyond the relatively short distance to the ISS could become impossible, or not time or cost effective. Future missions will need to rely on sustainable plant growth to supplement caloric intake, and the added benefit is that it is supposed to be an immense help for astronauts' mental health.

Kai Rasmussen, director of astrobotany.com

Below: Growing food in space is essential for long-duration spaceflight and future colonisation

© Getty

WHAT'S IN THE SKY?

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9 SEP
The eta-Perseids reach their peak of five meteors per hour

10 SEP
Conjunction between the Moon and Venus in Virgo

10 SEP
The Moon and Venus make a close approach, passing within 3°42' of each other in Virgo

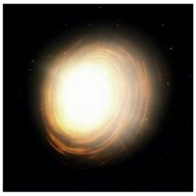
13 SEP
Mercury reaches greatest elongation east in the evening sky at magnitude +0.1

14 SEP
Neptune reaches opposition in Aquarius at magnitude +7.8

17 SEP
Conjunction between the Moon and Saturn in Capricornus

18 SEP
The Moon and Jupiter make a close approach, within 3°45' of each other in Capricornus

22 SEP
September equinox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1 OCT
Messier 110, a satellite galaxy of Andromeda, is well placed in the sky at magnitude +8.1

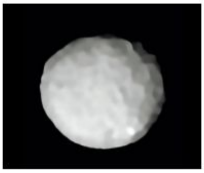
2 OCT
Asteroid 40 Harmonia reaches opposition in the constellation Cetus at magnitude +9.5

10 SEP

Comet 4P/Faye will approach the Sun, with a predicted brightness of +10.7 in Taurus

11 SEP

Asteroid 2 Pallas reaches opposition in Pisces at magnitude +8.6



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17 SEP

The Moon and Saturn make a close approach, within 3°40' of each other in Capricornus

18 SEP

Mercury reaches its half phase in the evening sky, shining brightly at +0.2

18 SEP

Conjunction between the Moon and Jupiter in Capricornus

24 SEP

The Moon and Uranus make a close approach, passing within 1°14' of each other in Aries

Source: Wiki Commons © Adam Evans

2 OCT

Messier 32, a satellite galaxy of Andromeda, is well placed in the sky at magnitude +8.1

2 OCT

The Andromeda Galaxy (Messier 31) is well placed in the sky at magnitude +3.4

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

RED LIGHT FRIENDLY

In order to preserve your night vision, you should read our observing guide under red light

JARGON BUSTER

Conjunction

This is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Greatest elongation

This is when the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as bright evening stars during greatest eastern elongations and as morning stars during western elongations.

Declination (Dec)

Declination tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

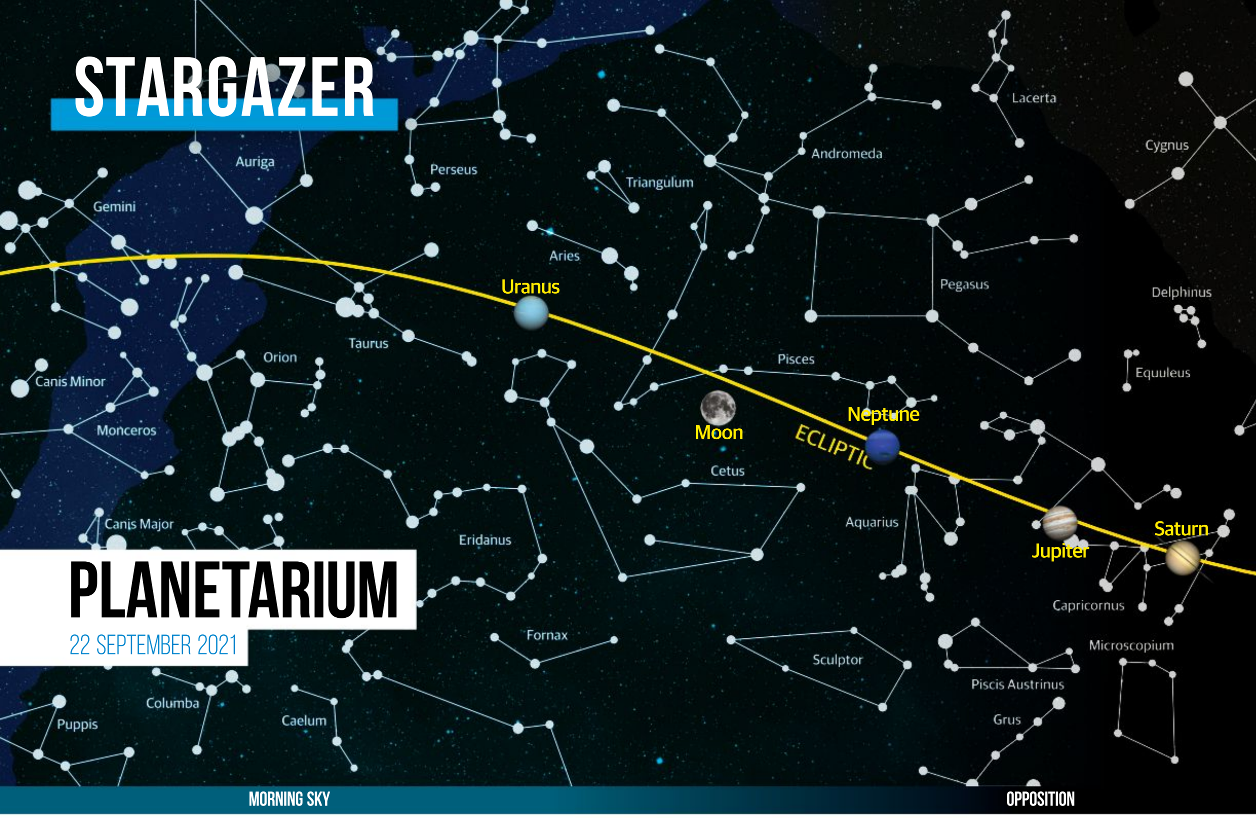
An object's magnitude tells you how bright it is from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object will be. So, an object with a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

This is when a celestial body is in line with the Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter in the sky.

PLANETARIUM

22 SEPTEMBER 2021



MOON CALENDAR

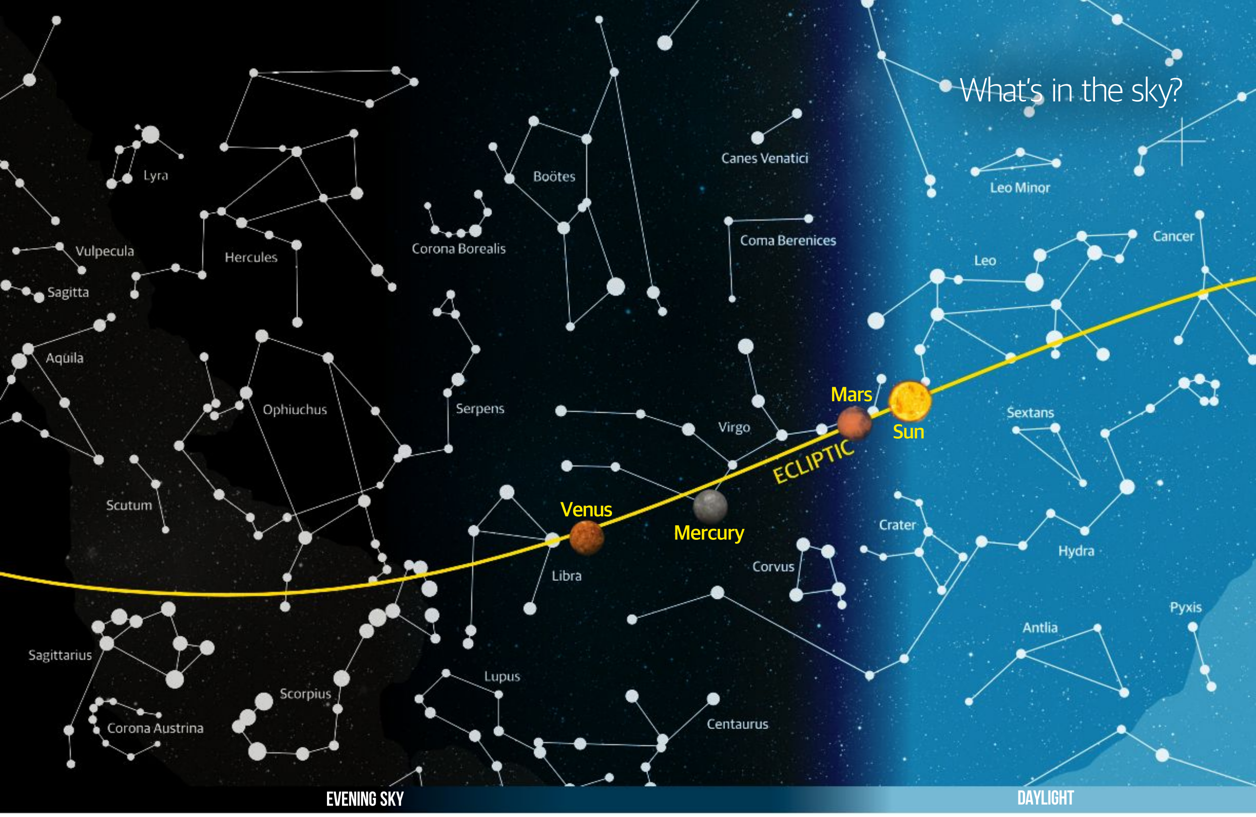
* The Moon does not pass the meridian on 19 September

Date	Phase	Illumination	Times
9 SEPT		8.4%	◓09:11 ◡20:45
10 SEPT		16.1%	◓10:35 ◡21:03
11 SEPT		25.8%	◓12:01 ◡21:24
12 SEPT		36.9%	◓13:27 ◡21:52
13 SEPT	FQ	48.7%	◓14:50 ◡22:29
14 SEPT		60.5%	◓16:05 ◡23:19
15 SEPT		71.6%	◓17:05 ◡--:--
16 SEPT		81.4%	◡00:24 ◓17:51
17 SEPT		89.3%	◡01:39 ◓18:24
18 SEPT		95.1%	◡02:59 ◓18:48
19 SEPT		--:--%*	◡04:19 ◓19:07
20 SEPT		98.7%	◡05:37 ◓19:23
21 SEPT	FM	99.8%	◡06:52 ◓19:37
22 SEPT		98.8%	◡08:06 ◓19:51
23 SEPT		95.6%	◡09:17 ◓20:05
24 SEPT		90.7%	◡10:29 ◓20:21
25 SEPT		84.2%	◡11:40 ◓20:40
26 SEPT		76.4%	◡12:50 ◓21:04
27 SEPT		67.7%	◡13:57 ◓21:35
28 SEPT		58.3%	◡14:59 ◓22:15
29 SEPT	TQ	48.5%	◡15:53 ◓23:07
30 SEPT		38.5%	◡16:37 ◓--:--
1 OCT		28.8%	◓00:10 ◡17:11
2 OCT		19.8%	◓01:22 ◡17:37
3 OCT		11.9%	◓02:40 ◡17:59
4 OCT		5.6%	◓04:00 ◡18:17
5 OCT		1.5%	◓05:22 ◡18:33
6 OCT	NM	0.1%	◓06:46 ◡18:49
7 OCT		1.7%	◓08:12 ◡19:06

%	Illumination	FM	Full Moon
◓	Moonrise time	NM	New Moon
◡	Moonset time	FQ	First quarter
		TQ	Third quarter

* All figures are given for 00h at midnight (local times for London, UK)

What's in the sky?



ILLUMINATION PERCENTAGE

	15 SEPT	22 SEPT	29 SEPT	6 OCT
MERCURY	50%	40%	30%	0%
VENUS	70%	70%	60%	60%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

PLANET POSITIONS

All rise and set times are given in BST

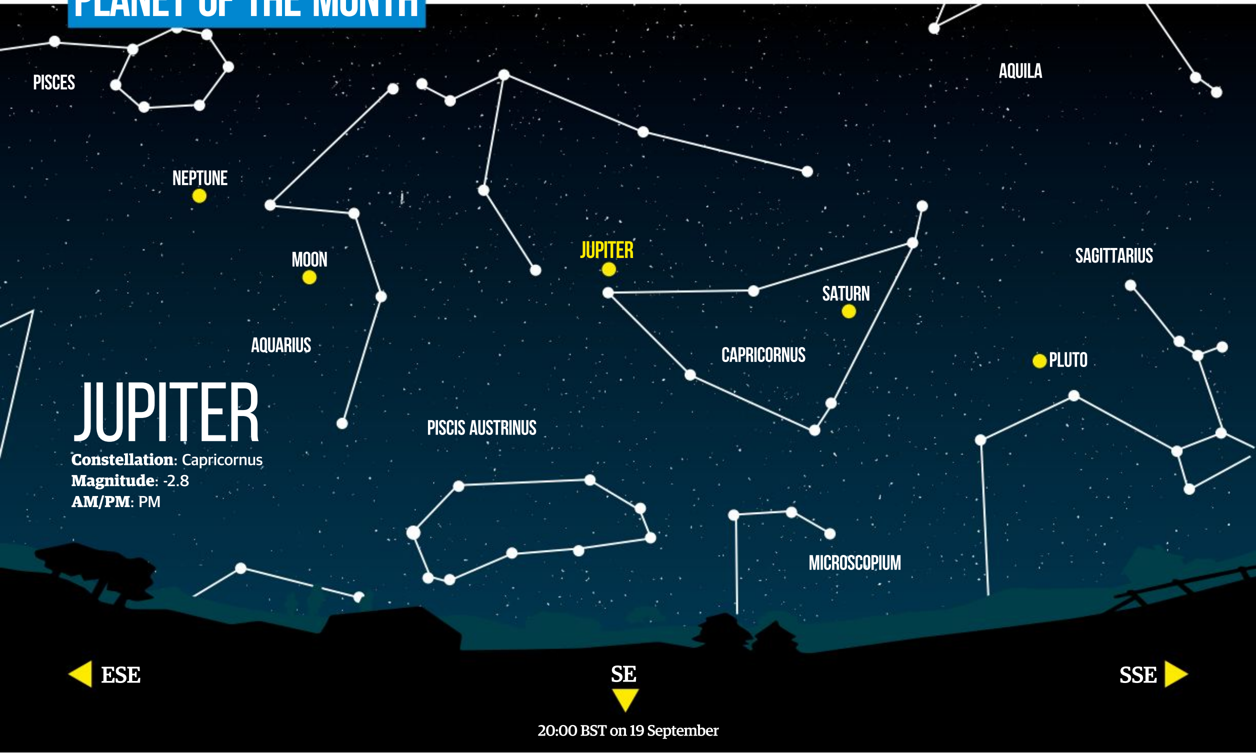
DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
9 SEPT	12h 42m 39s	-06° 39' 08"	Virgo	0.0	09:07	20:05
15 SEPT	13h 04m 47s	-09° 50' 40"	Virgo	+ 0.1	09:24	19:48
22 SEPT	13h 22m 51s	-12° 28' 50"	Virgo	+0.3	09:27	19:21
29 SEPT	13h 26m 59s	-13° 09' 32"	Virgo	+ 1.0	09:08	18:54
6 OCT	13h 11m 14s	-10° 41' 54"	Virgo	+ 3.6	08:11	18:24
9 SEPT	13h 41m 18s	-11° 14' 52"	Virgo	-4.1	10:29	20:37
15 SEPT	14h 07m 14s	-14° 02' 26"	Virgo	-4.1	10:49	20:25
22 SEPT	14h 37m 56s	-17° 04' 28"	Virgo	-4.1	11:08	20:08
29 SEPT	15h 09m 09s	-19° 48' 26"	Libra	-4.2	11:32	19:57
6 OCT	15h 40m 52s	-22° 10' 51"	Libra	-4.2	11:52	19:45
9 SEPT	11h 46m 02s	+02° 26' 46"	Virgo	+ 1.8	07:22	19:55
15 SEPT	12h 00m 10s	+00° 52' 18"	Virgo	+ 1.7	07:23	19:39
22 SEPT	12h 16m 44s	-00° 58' 27"	Virgo	+ 1.7	07:21	19:19
29 SEPT	12h 33m 25s	-02° 49' 18"	Virgo	+ 1.7	07:20	18:58
6 OCT	12h 50m 15s	-04° 39' 44"	Virgo	+ 1.7	07:20	18:38
9 SEPT	21h 48m 34s	-14° 30' 27"	Capricornus	-2.8	18:55	04:25
15 SEPT	21h 46m 05s	-14° 43 '06"	Capricornus	-2.8	18:31	03:59
22 SEPT	21h 43m 34s	-14° 55' 29"	Capricornus	-2.8	18:03	03:29
29 SEPT	21h 41m 34s	-15° 05' 01"	Capricornus	-2.7	17:32	02:56
6 OCT	21h 40m 07s	-15° 11' 29"	Capricornus	-2.7	17:06	02:28
9 SEPT	20h 40m 06s	-19° 12' 17"	Capricornus	+0.4	18:14	02:47
15 SEPT	20h 39m 00s	-19° 16' 34"	Capricornus	+0.4	17:53	02:25
22 SEPT	20h 37m 58s	-19° 20' 31"	Capricornus	+0.4	17:23	01:54
29 SEPT	20h 37m 14s	-19° 06' 19"	Capricornus	+0.5	16:54	01:25
6 OCT	20h 36m 49s	-19° 24' 49"	Capricornus	+0.5	16:29	01:00

STARGAZER

THIS MONTH'S PLANETS

Jupiter and Saturn are a dazzling duo from September through to October

PLANET OF THE MONTH



JUPITER

Constellation: Capricornus
Magnitude: -2.8
AM/PM: PM

20:00 BST on 19 September

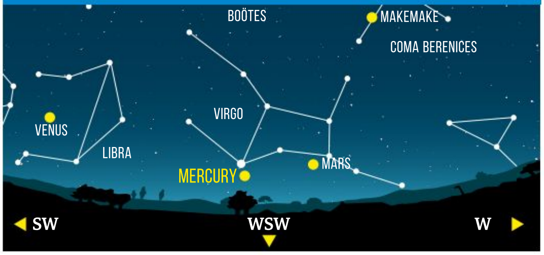
Jupiter will be visible all through the night, a lovely sight to the naked eye, through binoculars or in the eyepiece of a telescope. Finding it will be easy: as the western sky begins to darken, turn your back on the deepening twilight so you are facing the southeast and you'll see a blue-white 'star' glinting above the horizon. That's Jupiter, and as the sky darkens the planet will become brighter and more obvious until it's impossible to miss. Jupiter will be very obvious, looking like a bright 'star' to the left of fainter, more yellow-hued Saturn. At the start of our observing period it will set at around 04:30, and by mid-October will be setting at 02:00, but that will still give you plenty of time to enjoy observing it.

Through a modest pair of binoculars Jupiter will appear much brighter than it does to the naked eye, and you'll also see up to four of its extended family of more than 79 moons. We say 'up to' because the number you will see will depend on the date and time of night you're looking for them: as the moons whip around Jupiter they come in and out of view, moving in front of or behind their host planet, so sometimes you will be able to see all four of the so-called 'Galilean satellites' close to the planet, but at other times you might only see one or two. You can use the internet or phone apps to tell you in advance which moons you will be able to see on the night you're looking for them.

If you have a telescope, its higher power of magnification will show you details and features in the planet's atmosphere. You'll be able to see caramel and toffee-coloured cloud bands crossing the disc, and if you're looking at the right time you'll see the Great Red Spot too – a storm the size of Earth that has been raging in Jupiter's atmosphere for centuries.

However, if you want to see Jupiter in all of its banded, storm-spattered glory, you'll need to go online, to the website of NASA's Juno probe. It has sent back many thousands of stunningly detailed photographs of the planet's swirling storms, wild weather systems and billowing clouds, which you can see online for free.

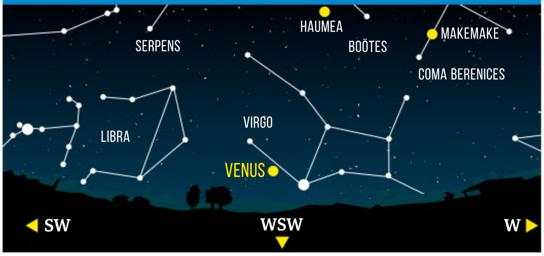
MERCURY 18:00 BST on 3 October



Constellation: Virgo **Magnitude:** -0.1 **AM/PM:** PM

At the start of our observing period Mercury will technically be an evening object, visible down to the lower right of much more obvious Venus, but it will be so close to the Sun, and setting so soon after it, that it will be challenging to see. The tiny planet might just be glimpsed through binoculars as a starlike point very low in the sky immediately after sunset.

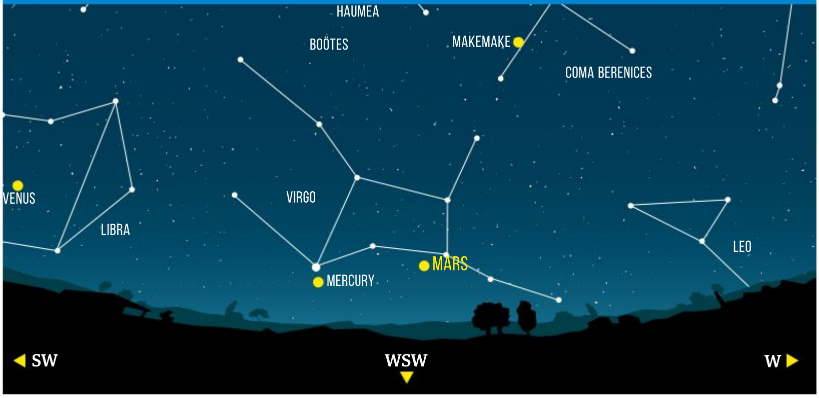
VENUS 20:00 BST on 9 September



Constellation: Virgo **Magnitude:** -4.1 **AM/PM:** PM

Venus will be easily visible to the naked eye, although it will be quite low in the sky and only visible for an hour or so before following the Sun behind the horizon. Venus will be shining at magnitude -4.1 to the upper left of tiny Mercury, easy to see even in the strong twilight, but as the days pass it will become progressively harder to see.

MARS 18:00 BST on 3 October



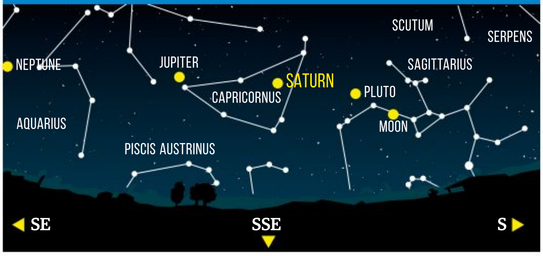
Constellation: Virgo

Magnitude: +1.8

AM/PM: PM

Mars is technically an 'evening star' this observing period, but it will be so low in the sky and so close to the Sun that it won't be visible. In fact, throughout the whole of our observing period for this issue the Red Planet will be impossible to view as it passes behind the Sun and is lost in its glare. You'll have to wait until next month to see it, when it will drift up into the morning sky. However, if you want to see Mars you'll still be able to by going online and viewing the galleries of amazing images sent back by NASA's Curiosity and Perseverance rovers.

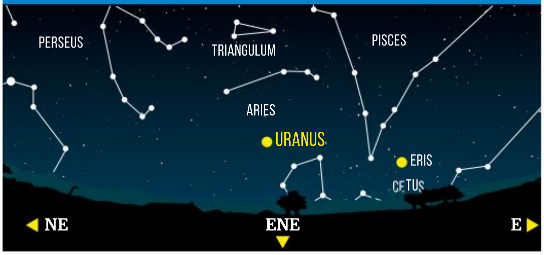
SATURN 21:00 BST on 15 September



Constellation: Capricornus **Magnitude:** +0.3 **AM/PM:** PM

Saturn will be a bright naked-eye object during the coming month. At the start of this issue's observing period Saturn will already be visible in the southeast as a yellow-hued 'star' to the right of brighter, bluer Jupiter as the Sun sets, and it will remain visible all through the night, only setting in the early hours of the next morning.

URANUS 20:00 BST on 13 October



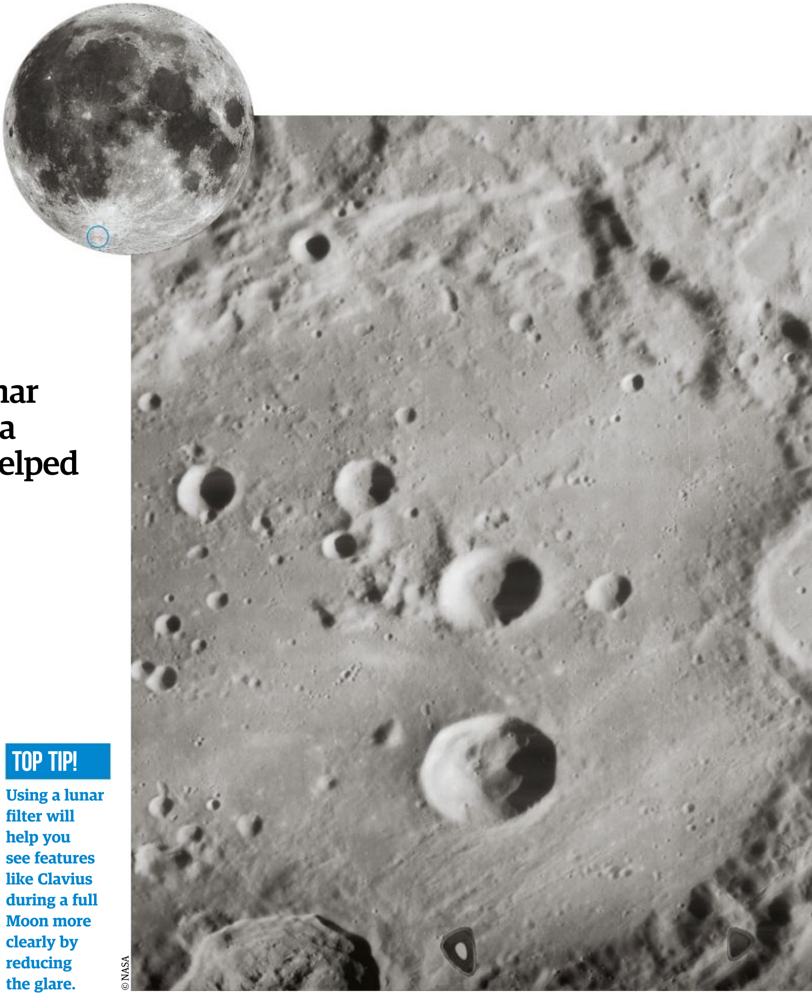
Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

Uranus will be a faint 'evening star', visible all through the night. At the start of our observing period this fascinating ice giant planet will rise at 21:00, and by mid-October will be rising two hours earlier than that. Magnitude +5.7 Uranus will technically be a naked-eye object – its subtle blue-green colour will help you identify it from the background stars.

MOON TOUR

CLAVIUS CRATER

Find one of the largest lunar impacts, made famous in a science-fiction film that helped shape the Space Age



© NASA

TOP TIP!

Using a lunar filter will help you see features like Clavius during a full Moon more clearly by reducing the glare.

If you're a fan of the classic 1968 science-fiction film *2001: A Space Odyssey*, this month's lunar 'celebrity feature' will need no introduction. Not the bright-rayed crater Tycho, where the alien monolith was unearthed; Tycho is 430 kilometres (267 miles) to the north of our destination: Clavius, a crater so huge it's easily visible to the naked eye when it lies near the terminator, appearing as an obvious notch between the areas of light and dark. Clavius' diameter of 225 kilometres (140 miles) makes it the third-largest crater on the side of the Moon that faces Earth. Binoculars and small telescopes reveal a wealth of detail in and around it. The first time you see Clavius with even a little magnification, you'll understand why this crater is a favourite object for many lunar observers.

Far away from any of the famous dark seas or historic Apollo landing sites, Clavius lies deep in the rugged and bright southern lunar highlands, 930 kilometres (578 miles) from the Moon's south pole, and is surrounded by countless other craters - large and small - on all sides. Its southerly latitude and proximity to the pole sadly means we don't see Clavius at its majestic best; our view of it is cruelly foreshortened by the curvature of the Moon. However, even a modest pair of binoculars will reveal a lot of fascinating detail in and around it.

You can pick out a quartet of smaller craters nestled within Clavius' shallow walls, arranged in a curving chain which arcs upwards from the southern rim to the north. Conveniently, the craters in the arc get progressively smaller in diameter the farther north they are, making this chain very useful as a test of an instrument's resolving power. A pair of binoculars will also show those crater walls themselves bear the scars of two huge ancient impacts: the oval, hummock-floored Rutherford crater to the south, and the rounder, flatter Proctor crater to the north are both easy to see at just 10x magnification.

But it is through a telescope that Clavius truly comes to life. At higher magnifications Clavius' floor appears spattered with countless craters - some forming short chains - but you'll need really high magnification to see those. Clavius' northern walls show themselves as extensively terraced and rippled. It's as if a section of that wall collapsed at some point in the distant past, sending a great tsunami of rock and dust sloshing towards the crater floor.

As is the case with all lunar features, you'll get your best views of Clavius when it is near or on the terminator - the line between lunar night and day. Then the sunlight will be slanting in at an angle, casting long shadows and highlighting the topography of the crater and its surroundings.

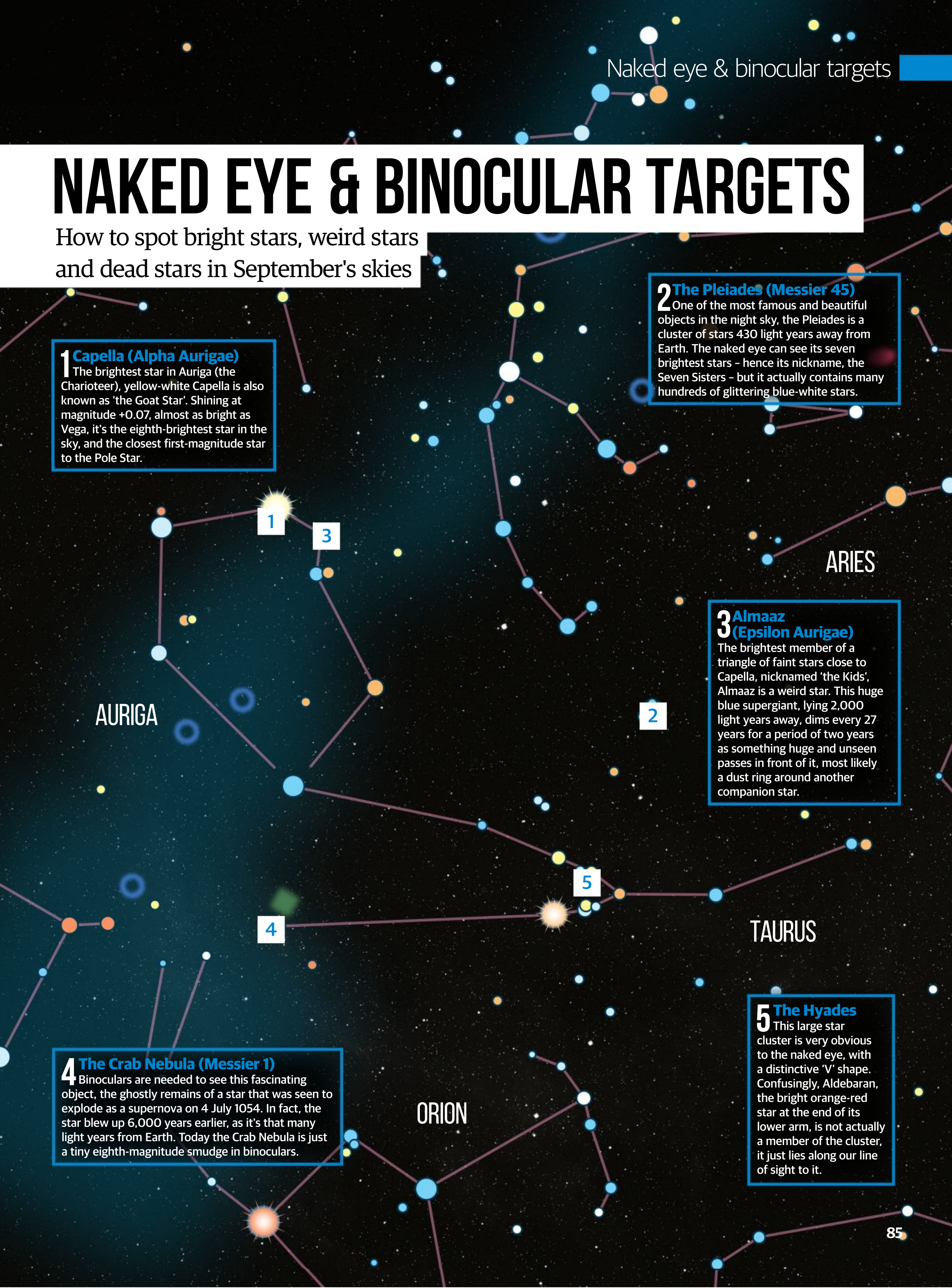
This month Clavius will be hidden until 29 September, when the Moon will have just passed first quarter. On that evening, the Moon will dip below the horizon in the northwest after sunset.

Over the next few evenings Clavius will look better and better, quickly emerging from the gloom of the long lunar night. Fully illuminated by the low Sun, its features will really stand out. By full Moon on 20 October, Clavius will be past its best, pretty much washed out by the light of the Sun blazing directly above it. The crater vanishes from view on 31 October, darkness crashing over it once more, and it won't become visible again until later in November.

As you look at Clavius through your binoculars or telescope, just think back to that classic scene from *2001* when the shuttle is landing at Clavius Base. Back in 1968, as NASA prepared to land people on the Moon, it seemed possible there would be such a facility in the year 2001, 33 years in the future. But today we're probably no closer to building such a base as we were back in 1968… a very sobering thought.

NAKED EYE & BINOCULAR TARGETS

How to spot bright stars, weird stars and dead stars in September's skies



1 Capella (Alpha Aurigae)

The brightest star in Auriga (the Charioteer), yellow-white Capella is also known as 'the Goat Star'. Shining at magnitude +0.07, almost as bright as Vega, it's the eighth-brightest star in the sky, and the closest first-magnitude star to the Pole Star.

2 The Pleiades (Messier 45)

One of the most famous and beautiful objects in the night sky, the Pleiades is a cluster of stars 430 light years away from Earth. The naked eye can see its seven brightest stars – hence its nickname, the Seven Sisters – but it actually contains many hundreds of glittering blue-white stars.

3 Almaaz (Epsilon Aurigae)

The brightest member of a triangle of faint stars close to Capella, nicknamed 'the Kids', Almaaz is a weird star. This huge blue supergiant, lying 2,000 light years away, dims every 27 years for a period of two years as something huge and unseen passes in front of it, most likely a dust ring around another companion star.

4 The Crab Nebula (Messier 1)

Binoculars are needed to see this fascinating object, the ghostly remains of a star that was seen to explode as a supernova on 4 July 1054. In fact, the star blew up 6,000 years earlier, as it's that many light years from Earth. Today the Crab Nebula is just a tiny eighth-magnitude smudge in binoculars.

5 The Hyades

This large star cluster is very obvious to the naked eye, with a distinctive 'V' shape. Confusingly, Aldebaran, the bright orange-red star at the end of its lower arm, is not actually a member of the cluster, it just lies along our line of sight to it.

DEEP SKY CHALLENGE

DISCOVER URSA MAJOR

Explore obscure deep-sky wonders lurking far beyond the stars of the Great Bear

Although far away compared to our own Sun, in cosmic terms the familiar stars of the Big Dipper are quite close to Earth – all between 80 and 123 light years away. But when you look at and through the Big Dipper, you're looking away from the Milky Way's cluttered star clouds, past its frothy, curving spiral arms and out into the endless depths of space. This month your deep-sky targets all lie many thousands or even many millions of light years away, and are all so faint you will definitely need a large telescope to see them all. Most are remote, exotic galaxies, far beyond the outer rim of our Milky Way, but one is a famously odd-looking planetary nebula, the ghostly remains of a once-proud star that exploded more than 6,000 years ago. Time to swing your telescope around to face north, slot in your best eyepiece and start hunting.

Owl Nebula (M97)

© Getty

NGC 5005

© NASA/ESA

Messier 109

Source: Wikipedia commons© Annelies Rhemrev

1 Messier 109 (NGC 3992)

This barred-spiral galaxy lies 84 million light years away. At magnitude +9.6, it only looks like a small pear-shaped smudge in small telescopes.

2 The Owl Nebula (M97)

This popular magnitude +9.8 planetary nebula has a blue-green tinge and a pair of dark lobes within its puffy disc which give it the look of an owl's face.

3 Messier 108

This edge-on spiral galaxy is 32 million light years away. Large telescopes show it as a small, faint streak with a bright centre and mottling along its length.

4 NGC 3928

This elliptical is so faint that it can only be seen through large-aperture instruments. Even then it is just a small, circular smudge in a high-power eyepiece.

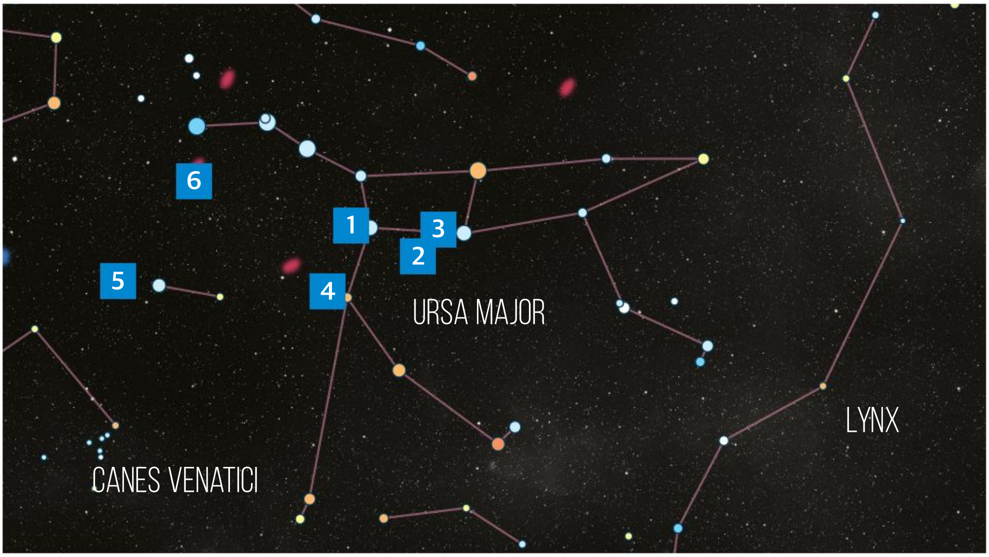
5 NGC 5005

This spiral is inclined to us, so large telescopes show it as a small, oval-shaped patch of light. High powers bring out hints of its dark dust lanes.

6 NGC 5173

This +12 elliptical is over 130 million light years away, so you'll need a large telescope to see it. Even then it will only look like a tiny, round smudge.

> "SPY REMOTE, EXOTIC GALAXIES, FAR BEYOND THE OUTER RIM OF OUR MILKY WAY"



THE NORTHERN HEMISPHERE

Darker nights are upon us, leaving astronomers to enjoy both Solar System and deep-sky objects

The constellations of autumn are starting to wheel into view, offering a wonderful selection of galaxies, open and globular star clusters. Globular clusters, including the Great Globular Cluster in Hercules (M13) and Messier 56 in Lyra (the Harp), as well as open cluster IC 4665 in Ophiuchus (the Serpent-bearer) are splendid evening targets. If you're keen to stay up until the early hours of the morning, you'll be rewarded as Taurus' Pleiades star cluster (M45) and spiral galaxies such as the Andromeda Galaxy (M31), nearby Triangulum Galaxy (M33) and face-on spiral Messier 74 in the constellation Pisces (the Fishes) make their appearance, becoming observable until sunrise washes them from view.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

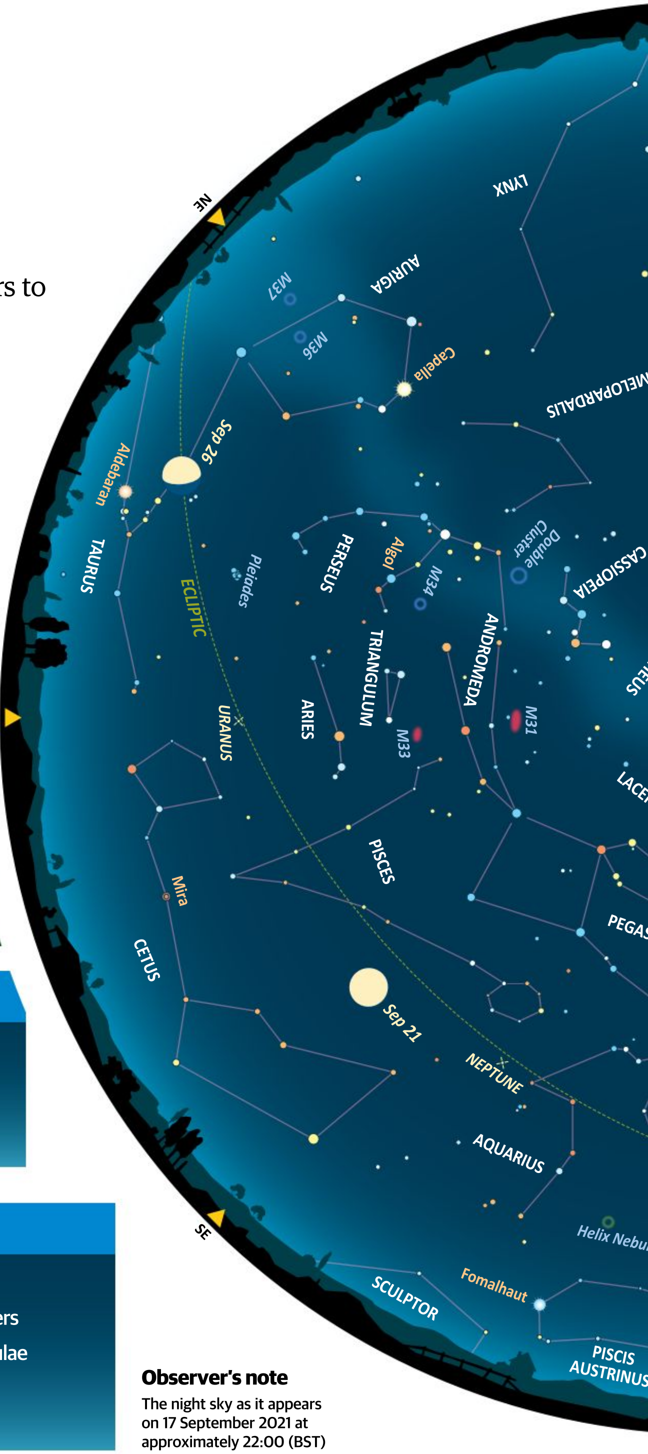
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- ● 1.5 to 2.0
- ● 2.0 to 2.5
- ● 2.5 to 3.0
- ● 3.0 to 3.5
- ● 3.5 to 4.0
- ● 4.0 to 4.5
- ● Fainter
- ● Variable star

SPECTRAL TYPES

- ● ● O-B
- ● ● A
- ● ● F
- ● ● G
- ● ● K
- ● ● M

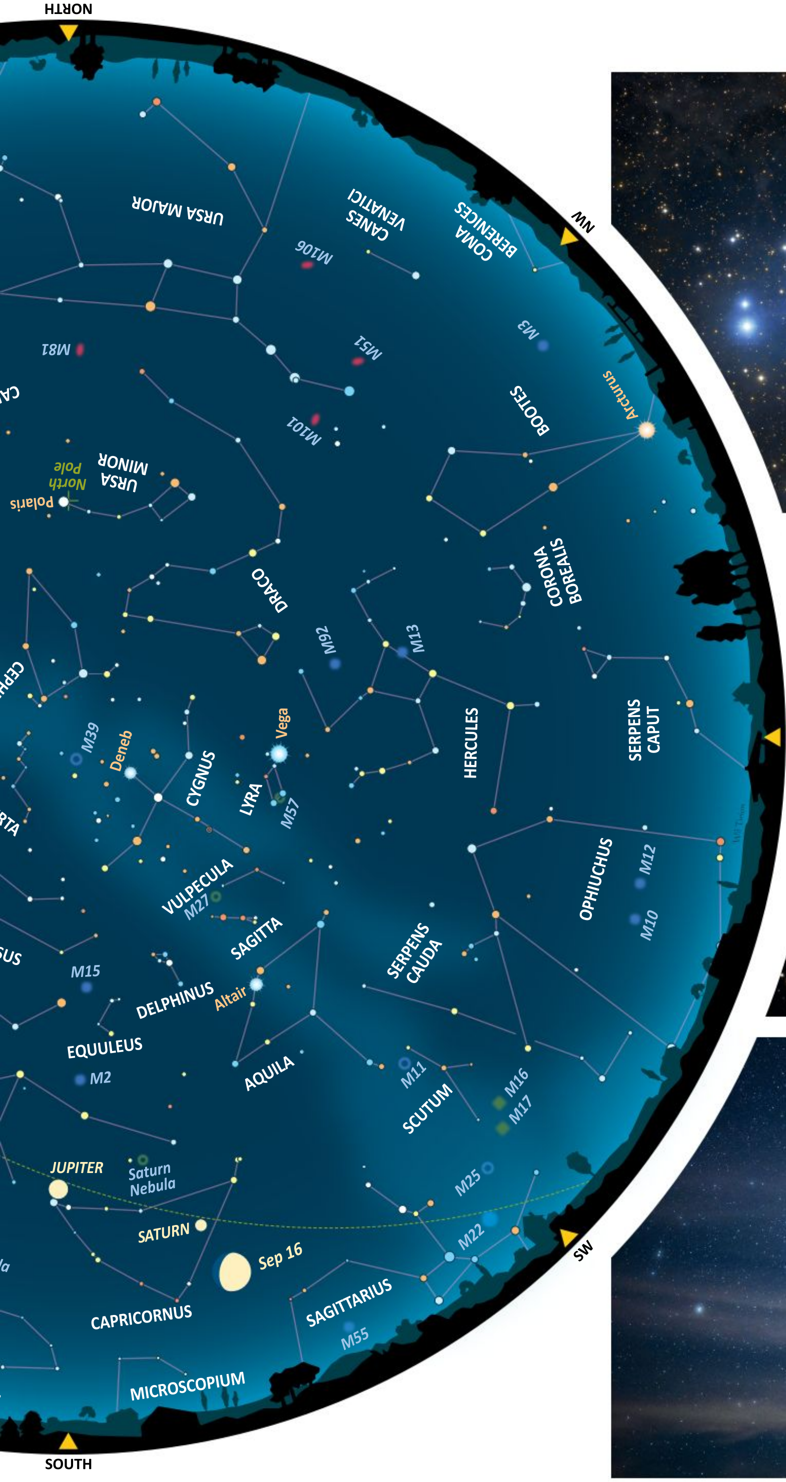
DEEP-SKY OBJECTS

- ○ ○ Open star clusters
- ● ● Globular star clusters
- ■ ■ Bright diffuse nebulae
- ○ ○ Planetary nebulae
- ● ● Galaxies



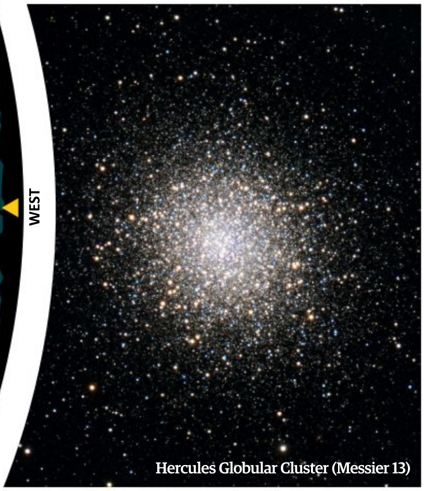
Observer's note

The night sky as it appears on 17 September 2021 at approximately 22:00 (BST)



Pleiades (Messier 45)

© Getty


Hercules Globular Cluster (Messier 13)

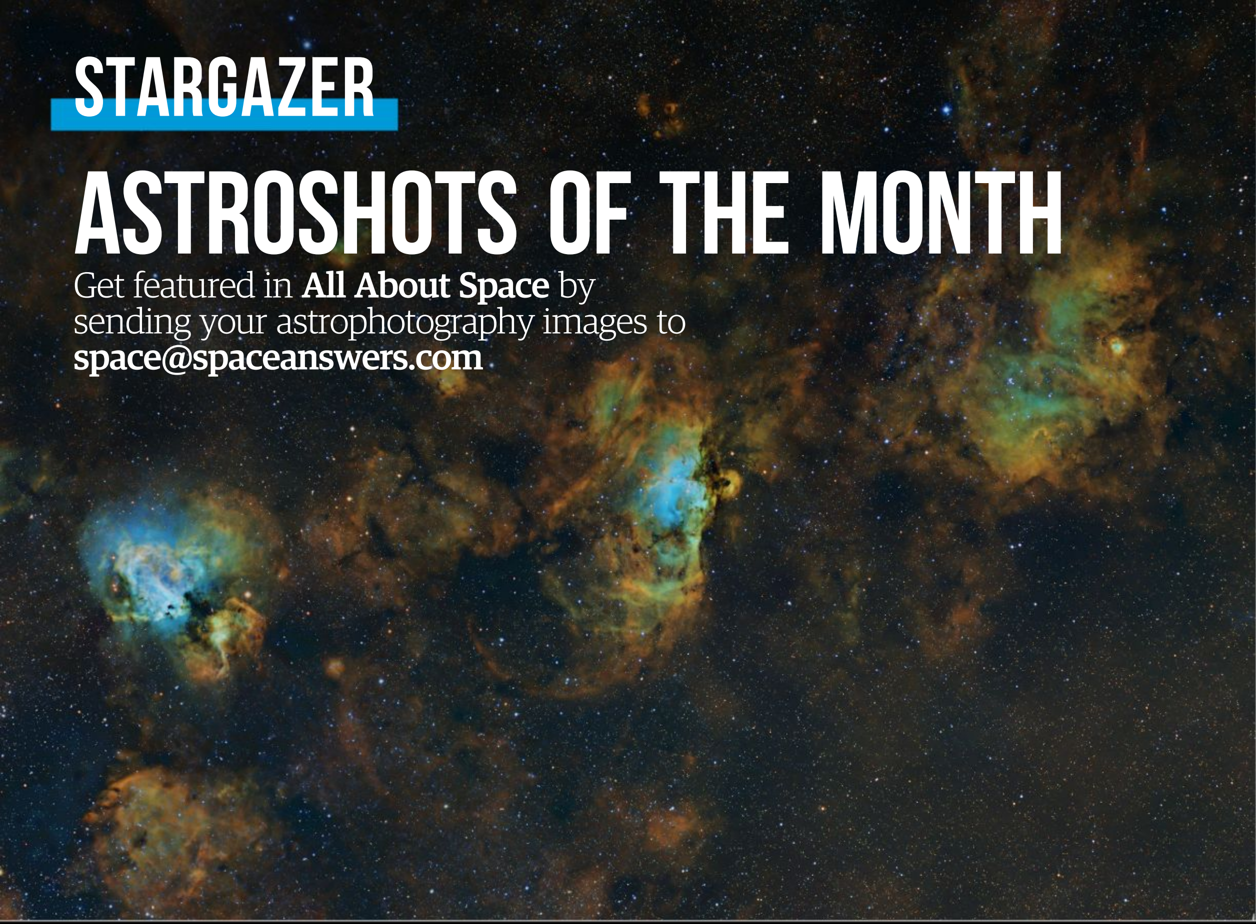
© Getty

Saturn and Jupiter

© Getty

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**



Terry Hancock

Location: Michigan

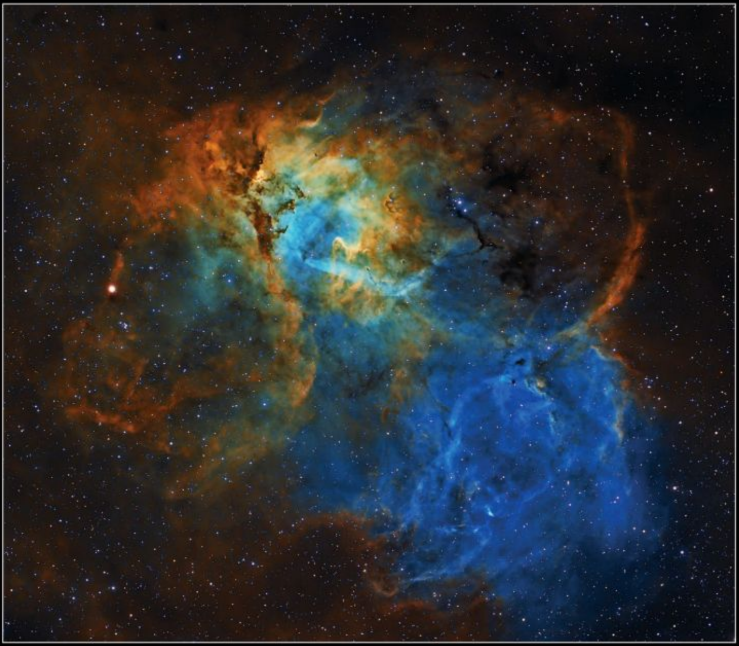
Telescope: Takahashi 130 FSQ

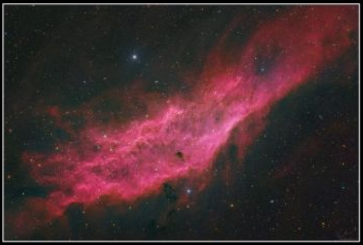
"My interest in astronomy began some 40 years ago in Australia. My first telescope was a 4.5-inch Newtonian, and I enjoyed many nights in the pollution-free, dark southern night skies of the hot Australian outback. It was often so dark that the Milky Way cast a shadow on the ground. I pride myself in taking really long exposures of deep-sky objects and always try to maintain a natural look."

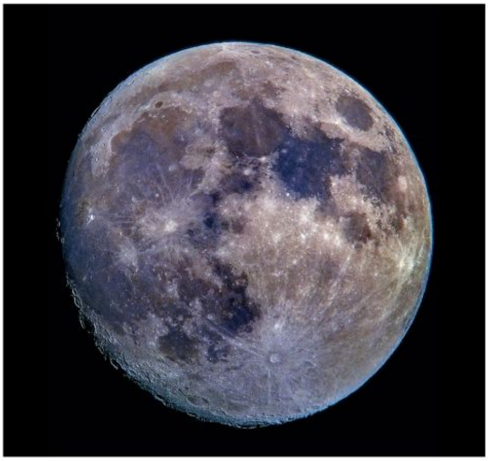
Above: Omega Nebula (Messier 17), Eagle Nebula (Messier 16) and open cluster NGC 6604

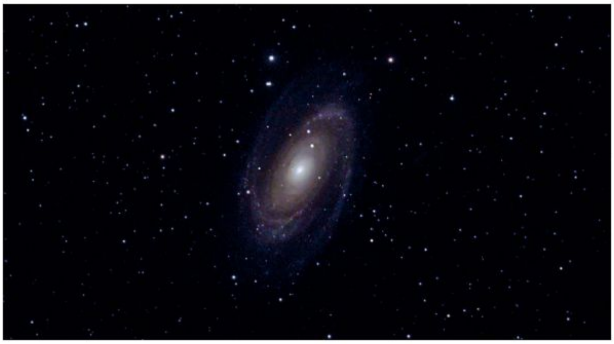
Right: Lion Nebula (Sharpless 132)

Below: California Nebula (NGC 1499)









> "ASTROPHOTOGRAPHY IS ALWAYS AN EXCITING THING TO DO WHEN THE SKIES ARE CLEAR"

Cristo Sanchez

Location: Yantis, Texas

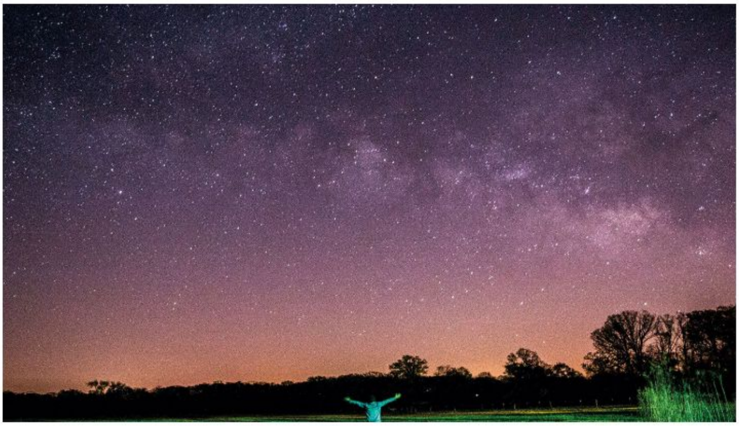
Telescope: Celestron Advanced VX 8 Reflector

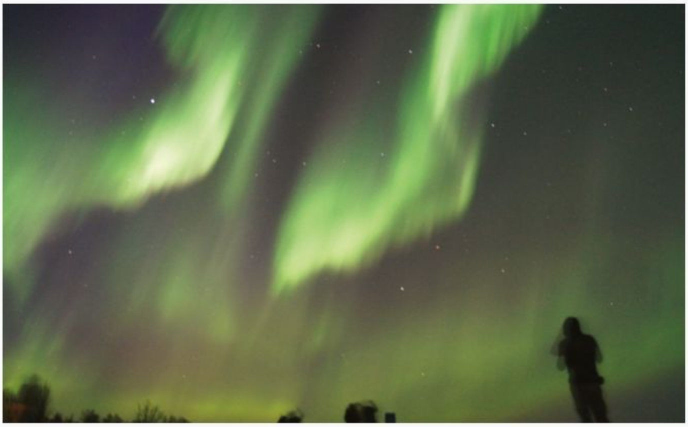
"My passion for astronomy began at the age of 12. From that point on I have studied, observed and photographically captured the cosmos. Shooting astrophotography is always an exciting thing to do when the skies are clear. Whether it's imaging planets, Messier objects or the Moon, it's always worth the long hours of capturing and processing your images. You get a great feeling seeing the final result and being able to share it with others in the community."

Above: Our natural satellite's cratered surface

Top right: Bode's Galaxy (Messier 81)

Right: The Milky Way's cloud band above the tree line





Left: Aurora borealis dancing in the night sky

Zofia Wolny

Location: Margate, Kent

"I haven't been interested in astronomy for very long – maybe about a year or so – but I took this image while on holiday in Iceland, as I enjoy photography and travelling. The aurora borealis was definitely something I was looking forward to on the trip, and seeing it with my own eyes really amazed me. I'm 14 now, so I have a long time to decide what I want to do when I'm older, but I'm sure it will be astronomy related. I love the subject!"

REVIEW

CELESTRON ASTROMASTER 130EQ

This reflector is great for observing the planets and bright sky objects, but absolute beginners will require patience with its mount

Reviewed by Damian Peach

TELESCOPE ADVICE

Cost: £174 (approx. $249.25)
From: Amazon
Type: Newtonian reflector
Aperture: 5.11"
Focal length: 25.6"

BEST FOR...

- BEGINNERS
- MEDIUM BUDGETS
- PLANETARY VIEWING
- BRIGHT DEEP-SKY OBJECTS

Choosing a telescope as a beginner is a process often fraught with pitfalls. These days we are spoilt for choice with the enormous range of equipment available. Telescopes for beginners are wide and varied, but some are most certainly better than others. The budget Celestron AstroMaster range seeks to reveal the wonders of the cosmos to those who are perhaps just taking their first steps into exploring an interest in the night sky without breaking the bank. In this review we test the 130mm-aperture reflecting telescope, which is available for under £200 – a great price for a complete telescope of this size.

The AstroMaster 130EQ comes supplied in a single box which includes the telescope optical tube, mount and accessories. Assembly of the whole telescope takes around 10 to 15 minutes and is very straightforward. The telescope is supplied with a German equatorial mounting, which unlike its more simplistic alt-azimuth counterparts requires a little more thought and patience to set up correctly.

The mount will require basic polar alignment for use under the night sky, which is a fairly easy process, especially if you are just using the telescope for visual use. A rough alignment of the polar axis towards the celestial pole is easily good enough.

The telescope itself is a 130mm Newtonian reflector. Its focal ratio of f/5 means it is a fast telescope more suited to general lower power viewing of celestial objects. The telescope tube itself attaches to a German equatorial mount with manual dual-axis slow-motion controls.

The telescope and mount are nicely made and are of good quality. One especially nice point that is quickly realised is how lightweight and portable this system is. One person can easily move around the entire telescope with no problem. Assembly is simple and straightforward following the included instructions. The telescope itself is moved manually – either by pushing the telescope tube with your hand or using the slow-motion control knobs for fine adjustments.

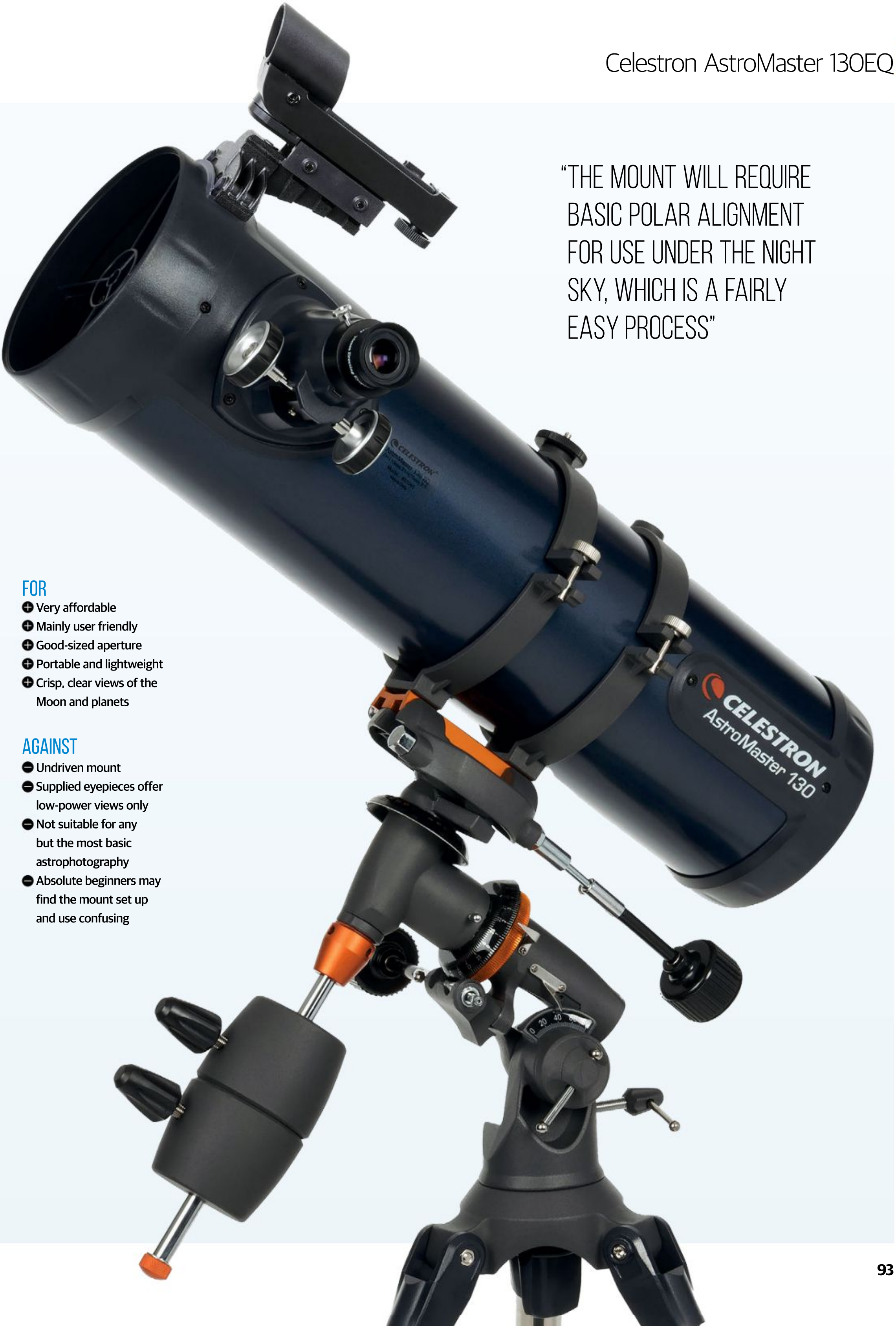
Being a Newtonian telescope, it's very important to collimate it before use, and this is also quite easy to achieve following the included instructions. We cannot stress how important this is if you really want to get the most out of the AstroMaster 130EQ – it will make a significant difference to your enjoyment of the telescope.

The telescope comes with two eyepieces – a 20mm and 10mm, giving powers of 33x and 65x respectively, both suitable for low-power wide-field observing. If you wish to use higher powers, we'd recommend purchasing a good-quality Barlow lens. To see details on the planets you will need magnifications of at least 150x, which is well above what the included eyepieces offer.

Once set up and collimated, you are ready to begin observing. Star testing the telescope at higher powers revealed well-corrected optics, and stars focused nicely into tiny airy discs, as you would expect from a good-quality optical system – a very promising first sign!

Main: The telescope and mount are sturdy and well-made, while also lightweight

Left: 20mm and 10mm eyepieces are supplied with the AstroMaster



> “THE MOUNT WILL REQUIRE BASIC POLAR ALIGNMENT FOR USE UNDER THE NIGHT SKY, WHICH IS A FAIRLY EASY PROCESS”

FOR

- ⊕ Very affordable
- ⊕ Mainly user friendly
- ⊕ Good-sized aperture
- ⊕ Portable and lightweight
- ⊕ Crisp, clear views of the Moon and planets

AGAINST

- ⊖ Undriven mount
- ⊖ Supplied eyepieces offer low-power views only
- ⊖ Not suitable for any but the most basic astrophotography
- ⊖ Absolute beginners may find the mount set up and use confusing

Our first proper target for the telescope was the giant planet Jupiter, shining brightly in the south, which was only a month away from opposition. We moved the telescope tube manually by pushing it slowly towards the target. The motion was smooth and didn't require much force. The small red-dot finder helped to centre the target within the main telescope's field of view. Upon gazing in using the 20mm eyepiece, at 33x we could quickly see Jupiter's flattened disc with the bright Galilean moons either side of the planet. Moving the power up to 66x using the 10mm eyepiece revealed a few belts and zones visible across the Jovian disc. The view was very sharp and clear, and really asked for higher power. This is perhaps where the telescope would benefit from having a Barlow lens or a higher power eyepiece included.

Thereafter we decided to move to nearby Saturn. The famous rings of the planet were easily observed, with some of the planet's brighter moons seen alongside it. We decided to up the power using some of our own equipment, installing a 2x Barlow and increasing the magnification to 120x. The Cassini division in Saturn's ring system was easily observed, as well as cloud bands on the disc of the planet – an impressive performance for such a low-cost telescope. We quickly moved back to Jupiter, and details could be seen within the cloud belts of the planet. Ganymede – Jupiter's largest moon – also presented a tiny disc.

We also took some time to observe some fainter targets. The Dumbbell Nebula is a bright planetary nebula well visible in small telescopes. Through the AstroMaster 130EQ it was a clear, bright view, and the nebula clearly showed some of its double-lobed shape. We then moved over to the famous globular star cluster Messier 13. The cluster showed a myriad of pinpoint stars with resolution right into the core of the cluster. We've viewed this cluster through countless telescopes over the years, and the AstroMaster 130EQ certainly gave an impressive view for a small telescope. Of course, with a 130mm aperture you are perhaps somewhat limited in hunting down fainter nebulae and galaxies, but under a dark sky it certainly has enough light-gathering power to show many interesting and varied targets.

While the AstroMaster 130EQ is undoubtedly a fine telescope for visual observing, it is not well suited to astrophotography. Since the mount is undriven, long-exposure work is impossible. You can take simple afocal images by holding a phone to the eyepiece or by using an adapter to attach your phone or camera, but more advanced work will prove frustrating. You should remember, however, this telescope isn't really designed with that in mind. It's certainly more than good enough to make some first photographic attempts with.

Overall, the AstroMaster 130EQ is a nice telescope for the beginner or those just starting out. It would make an ideal gift to the budding young astronomer – we can only imagine how delighted we would have been to have received such a telescope back when we started out. Another great point here is the affordable price tag; you get a very capable system for your money.

No telescope is perfect, however, and this is no exception. It would be good to see a higher power eyepiece or Barlow lens included to allow higher power views of the planets – essential if you wish to see details on them. Another point worth mentioning is that the telescope must be collimated to perform properly, and collimation isn't the simplest task for the beginner, especially with a Newtonian. That said, the small size of the 130EQ makes the process far more rapid than on larger telescopes, where you are constantly moving between collimation screws and the eyepiece. The mount may prove a little tricky to get to grips with for those with no experience, and an alt-azimuth mounted alternative may be a better option for an absolute beginner. This AstroMaster 130EQ is a great choice for a first telescope or for those just starting out: it offers impressive views of a wide range of different objects and would make a great present for a budding astronomer.

> "UPON GAZING IN USING THE 20MM EYEPIECE, WE COULD QUICKLY SEE JUPITER'S FLATTENED DISC, WITH THE BRIGHT GALILEAN MOONS EITHER SIDE OF THE PLANET"

Right: The mount could easily be upgraded to one with built-in tracking

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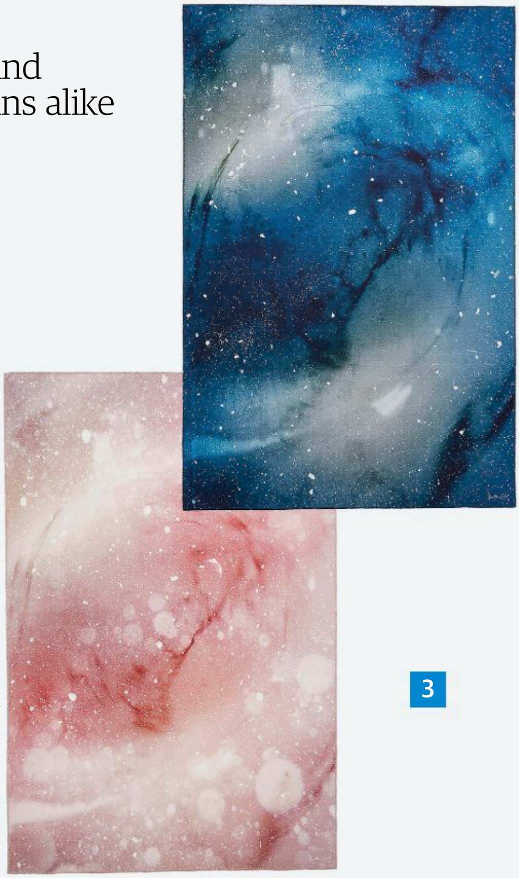

3

1

FOR TEATIME

ROCKET TEA INFUSER

Cost: £3.00 / $4.16

From: therefilljar.co.uk

1 Add some fun to your morning brew with this charming rocket-shaped tea infuser. Simply add the loose tea and leave it in a cup of water – hot or cold – to infuse for as long as you need to create the perfect strength cup of tea. The lightweight stainless-steel rocket infuser is easy to clean due to the hinged design, and also comes with a handy drip tray.

FOR YOUR WARDROBE

SCIENCE MUSEUM SPACE JUNK T-SHIRT

Cost: £25 (approx. $34.15)

From: shop.sciencemuseum.org.uk

2 There are currently over 170 million pieces of space debris in orbit around Earth; it is one of the largest space problems, and we are not talking about it enough. This striking space junk T-shirt from the Science Museum makes for the perfect conversation starter. The T-shirt illustrates what all this debris looks like in space and conveys the sheer scale of the problem. Made from 100 per cent premium cotton, this T-shirt is both durable and comfortable. It's available in sizes small, medium, large and extra large.

FOR YOUR HOME

MICHELLE COLLINS COSMIC RUG

Cost: From £79 (approx. $108)

From: dunelm.com

3 This stunning rug features a beautiful cosmic scene created by the talented artist Michelle Collins. The artwork has been digitally printed onto the rug, which is sure to make a statement in any room. It's available in two colourways: Cosmic Rose and Cosmic Navy. It's also available in two sizes: 120 by 170 centimetres (47 by 67 inches) and 150 by 230 centimetres (59 by 90.5 inches). The flatweave pile ensures this rug is relatively easy to care for, making it a perfect addition to your home.

“THESE LITTLE PLANTERS ARE PERFECT FOR A SMALL SUCCULENT OR AIR PLANT”

FOR FUN

ESTES SPACE CORPS DARC-1

Cost: £24.99 / $29.99

From: alshobbies.co.uk / estesrockets.com

4 Model rocket maker Estes has unveiled its newest expert-level rocket, the DARC-1, as the latest addition to its Space Corps line – DARC stands for Deep Atmospheric Research Craft. The model has a length of 23.6 centimetres (9.3 inches), as well as a projected maximum altitude of 122 metres (400 feet) using Estes’ B6-2, C5-3 or C6-3 size motors. The model rocket itself is on sale for £24.99, but you will need a launch pad, launch controller – and batteries – Estes model rocket motors, starters and recovery wadding for a successful launch, which are all sold separately.

FOR OBSERVING

EXPLORE SCIENTIFIC POP-UP TWO-ROOM OBSERVATORY

Cost: £233 / $279.99

From: telescopehouse.com / telescopes.net

5 Kit yourself out for the start of astronomy season with this handy portable tent observatory. Protect your astroimages from wind, stray light and weather, so that blurred and dazzled images become a thing of the past. The roomy design includes two separate rooms, each 1.52 by 1.52 metres (5 by 5 feet), so there is plenty of space to house your equipment. The tent is also easy to transport, measuring just 70 by 10 centimetres (27.5 by 3.9 inches) folded and weighing three kilograms, making it the ideal astronomy companion.

FOR DECORATION

MINI PLANET PLANTERS

Cost: £15.99 / $23

From: thetrouvailles.com

6 Spruce up your office space or home with these quirky little planet planters. Available in three colourways – white, tan and blue – there’s a mini planet for every room and mood. Measuring 12 by 7.5 centimetres (4.7 by 3 inches) and with an opening of five centimetres (two inches), these little planters are perfect for a small succulent or air plant. An ideal gift for yourself or a fellow space and plant lover.

HEROES OF SPACE

Roman became the first female executive at NASA

© Getty

NANCY ROMAN

A pioneering astronomer who came to be known as the 'Mother of Hubble'

Roman was an influential astronomer and a champion of research and engineering. Her passion for a shared understanding of the cosmos made her a key advocate for NASA's Hubble Space Telescope. Her fascination with astronomy began at a young age, when her mother would take her out for walks and point out the constellations above. At school Roman created an astronomy club with her friends, where they would study the constellations, and by the time she was 12, Roman had decided that she wanted to be an astronomer.

Despite her dedication and passion for astronomy, her path to becoming an astronomer was saturated with people trying to convince her to pursue other interests. In an interview with NASA, Roman recollected a conversation she had with her school guidance counsellor where she recalled asking permission to take second-year algebra instead of fifth-year Latin, to which her guidance counsellor replied: "What lady would take mathematics instead of Latin?" Astonishingly, in the same interview Roman revealed that the first bit of encouragement - if you can call it that - she received was at college when the head of physics told her: "I usually try to talk women out of going into physics. But I think maybe you might make it."

In 1949 Roman proved the head of physics right when she achieved a doctorate in astronomy from the University of Chicago. She published numerous scientific papers, including one containing the spectral types, photoelectric magnitude and colours and spectroscopic parallaxes for about 600 high-velocity stars. Roman also made some significant scientific breakthroughs when she realised that stars made of hydrogen and helium move faster than stars composed of heavier elements.

A decade after achieving her doctorate, Roman took a job at NASA, where she became the first chief of astronomy in the Office of Space Science. This was a significant milestone in both Roman's life and NASA's history, as she became the first woman to hold an executive position at the space agency. One of Roman's primary responsibilities during her time with NASA involved the Hubble Space Telescope. It was up to Roman to convince people that this venture was worth pursuing. She assembled a team of astronomers and NASA engineers to come up with ideas that not only engineers thought were feasible, but that astronomers thought were useful. Roman armed herself with as much information as possible to convince NASA, the United States Bureau of the Budget (now known as the Office of Management and Budget) and Congress that the Hubble Space Telescope was a project worth carrying out.

She was successful in her efforts, and played a large part in eventually getting Hubble off the ground in 1990. At the time, Princeton astronomer Lyman Spitzer was also a huge advocate for placing a telescope in space, beyond Earth's atmosphere. As such, he was nicknamed the 'Father of Hubble'. According to Roman in a NASA interview, the former head of NASA's Science Mission Directorate Ed J. Weiler said if Spitzer was going to be the father of the telescope, then Roman should be the mother - the nickname stuck. Throughout her distinguished career, Roman worked on various NASA programs with astronomers at the forefront of astronomical research, and also the broader worldwide astronomical community.

Roman passed away on 25 December 2018, aged 93. In May 2020 NASA announced that its next-generation space telescope, now set to launch in 2025, the Wide Field Infrared Survey Telescope (WFIRST), would be renamed in her honour and known as the Nancy Grace Roman Space Telescope, or Roman for short. "Her name deserves a place in the heavens she studied and opened for so many," said NASA's associate administrator for science Thomas Zurbuchen.

All About Space

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